SEWAGE WORKS JOURNAL

VOL. XII MAY, 1940 No. 3

Special Articles

High Rate Filters—Keefer and Kratz

Copperas-Silica Coagulant—Hurwitz and Williamson

Oil and Grease in Sewage—Mahlie

Buffalo River Pollution—Symons and Torrey

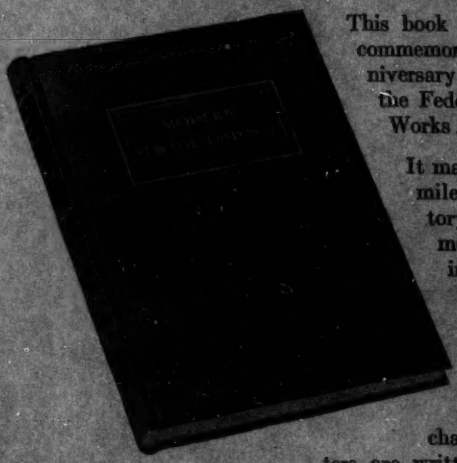
Raritan River Pollution—Forman and Johns

Sewage Sedimentation—Wittwer

ANNOUNCEMENT
First Annual Convention
See Page 634

OFFICIAL PUBLICATION OF THE
FEDERATION OF SEWAGE WORKS ASSOCIATIONS

MODERN SEWAGE DISPOSAL



This book was published to commemorate the Tenth Anniversary of the founding of the Federation of Sewage Works Associations.

It marks an important milestone in the history of sewage treatment. It is unique in the field of sewage and industrial waste disposal.

It covers 371 pages and contains thirty-two chapters. The chapters are written by authorities distinguished in their respective fields. The topics cover processes of sewage treatment, disposal of effluents, research in the laboratory and plant, disposal of industrial wastes, and regional and national aspects of sewage disposal.

As a publication of the Federation of Sewage Works Associations, this reference manual has been priced so as to become available to the greatest number.

Copies are sold as follows:

To subscribers of SEWAGE WORKS JOURNAL, $2.50 per copy.

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A Bimonthly Journal devoted to the advancement of fundamental and practical knowledge concerning the nature, collection, treatment and disposal of sewage and industrial wastes, and the design, construction, operation and management of sewage works.

Publication Office: Prince and Lemon Sts., Lancaster, Pa.

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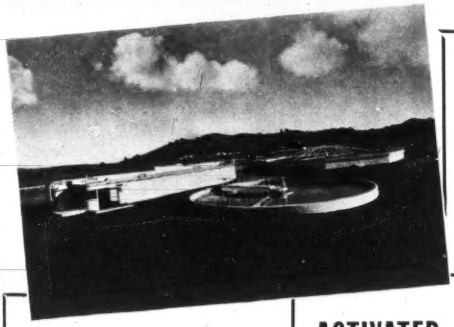
BIOFILTRATION AT PETALUMA



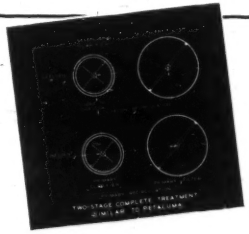
Left: Biofiltration System at Petaluma, Cal.

ADVANTAGES COMPARED WITH STANDARD TRICKLING FILTER PRACTICE

- Uniform final effluent
- Filter loadings up to 10 times normal
- Shallow filters—3 ft. media depths
- Installed costs 25 to 35 percent less
- Operating costs 30 to 40 percent less

TWO-STAGE BIOFILTRATION AT PETALUMA, CAL.

Test No.	1	2
Flow—M.G.D.	.503	.500
Dosing Rate Raw—M.G.A.D.	5.05	10.6
Total—M.G.A.D.	17.2	37.1
Sus. Solids—PPM		
Raw	424	462
Final	33	43
Removal—percent	92.3	90.7
B.O.D.'s—PPM		
Raw	576	521
Final	14	28
Removal—percent	97.6	94.6
Raw B.O.D. Loading		
Lbs. cu yd/day	2.47	4.78



ACTIVATED SLUDGE RESULTS AT LESS THAN TRICKLING FILTER COSTS

★ At Petaluma, California, the total plant cost, excluding the pumping station, was $101,000* per million gallons of design capacity—25 to 35 percent less than a Standard Trickling Filter installation. Yet the results obtained are directly comparable with Activated Sludge practice.

The Biofiltration System, marketed by us, is represented by 14 operating installations and by 7 additional units now under contract. By recycling the filter discharge back to the clarifier, it makes it possible for the first time to control the trickling filter operation.

* Includes $16,000 worth of special piling and soil compacting.

● *Why not write for a complete technical report and operating data on Biofiltration—or better still, ask one of our engineers to call and explain it in person?*

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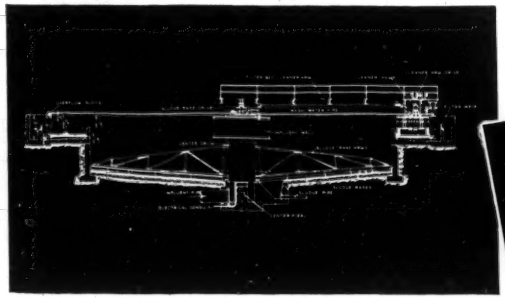
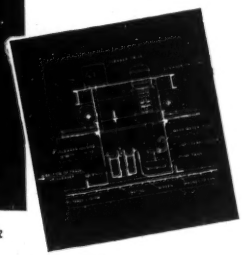


1. Magnetite Filter installed integral with round clarifier tank



2. Close up of magnetic bed cleaning element

Use AUTOMATIC MAGNETITE FILTERS

APPLICATION

In Plain Sedimentation
Less settling capacity required and a 40 per cent improvement in effluent.

In Chemical Precipitation
50 per cent less chemical consumption; less time for coagulation and settling.

In Activated Sludge
Less settling and aeration tank capacity; less compressed air.

In Trickling Filters
If ahead, less primary settling tank capacity. If behind, less humus tank capacity.

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The Automatic Magnetite Filter consists of a 3 inch layer of carefully sized magnetic iron ore, supported by a non-corrosive screen, and agitated by a moving solenoid which periodically lifts and releases a narrow strip of ore. A counter-flow of wash water, introduced as the layer is lifted, carries off the fine particles caught by the bed and renews the life of the filter medium.

Write for your copy of the Automatic Magnetite Filter Bulletin.

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BETTER MIXING . . . GREATER SAVINGS O
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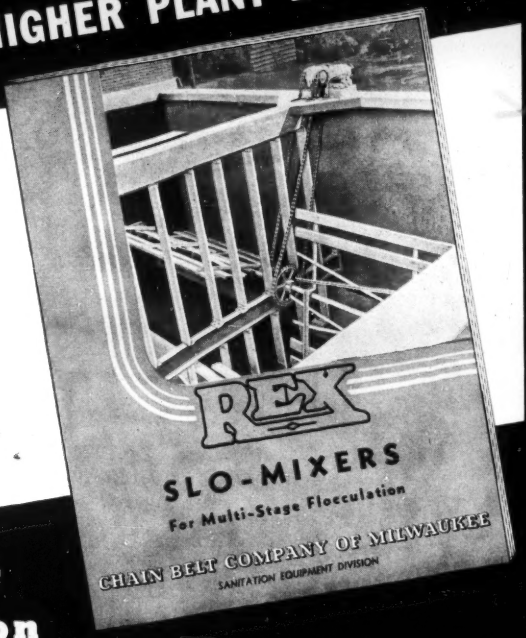

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REX SLO-MIXERS!

Just off the press, this brief, concise folder tells the whole story of Rex Slo-Mixers' many new advantages for use in multi-stage flocculation! If you are operating a flocculation process or thinking of installing one, here's the latest news on the newest method for providing the right turbulence for maximum floc formation. Send for your copy now!

Ask about Rex Sludge Collectors!

At the same time, ask for your copy of the books, "Rex Conveyor Sludge Collectors" and "Rex Tow-Bro Sludge Removers"—which describe in detail the design and application of Rex sludge-removing equipment in sewage and water treatment plants the country over! Don't modernize any plant—or design a new one—without learning about the new efficiency you can expect with Rex sanitation equipment! Address the Chain Belt Company, 1606 W. Bruce St., Milwaukee, Wisconsin.

REX CHAIN BELT COMPANY of Milwaukee

SANITATION EQUIPMENT

Sorry! No action in this aeration tank the day this photograph was taken at the Atlanta, Georgia, sewage treatment plant. But you should see it normally; every plate at work, each receiving its full quota of air.

Burger diffuser plate holders help the sewage treatment plant maintain its high efficiency. They are made of Alcoa Aluminum, so are able to withstand the corrosive attack of the sewage. There's no rusting to cause clogging of the plates.

The light weight of Aluminum, coupled with the convenience of the Burger design, makes the task of maintaining the aeration system an easier one. Holders carrying a number of diffuser plates are handled as a unit. Plates are removed quickly, without danger of breaking them; they are quickly replaced and made water- and air-tight against long-lived rubber gaskets.

It will pay you to investigate the moneysaving possibilities of this holder and of the use of Aluminum Alloys elsewhere in sewage treatment processes. ALUMINUM COMPANY OF AMERICA, 2111 Gulf Building, Pittsburgh, Pennsylvania.

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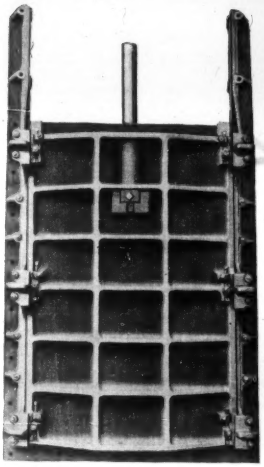
STANDARDIZED SLUICE GATES

Chapman Sluice Gates are outstanding in all fields of application. Every gate is backed by a heritage of seventy-five years of successful experience in sluice gate design and manufacture. From this rich experience, Chapman has developed standardized lines embracing a range of types and sizes to meet all usual conditions, at substantial savings in cost and time of delivery. Interchangeable parts also facilitate installation and reduce cost of repairs or replacements in the field. Check your specifications with Chapman's *Sluice Gate Handbook*. Copy on request.



7′ x 7′ Table 6 Sluice Gate Adjustable Side Wedges, Rising Stem Type

Chapman

Automatic Cone Valves

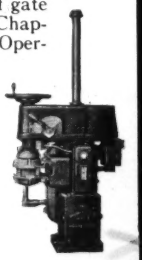
Cut-Away View Automatic Cone Valve

Chapman Automatic Cone Valves are ideally suited for a number of important uses in sewage treatment, due to their smooth waterway and positive operation.

Recommended for: Sewage pump discharge check valves; Control of sludge chamber levels; Quick operating for grit chambers; Air blower checks on activated sludge.

Motor Units & Floorstands

For the electrical operation of gate valves and sluice gates, the Chapman Motor Unit and Motor Operated Floorstand will be found highly efficient and dependable. They are rugged and extremely simple, and may be operated at the unit or by remote control. Seating to any predetermined tightness is controlled by the Chapman *Limit Switch*, eliminating all possibility of jamming.



Motor Operated Floorstand

THE CHAPMAN VALVE

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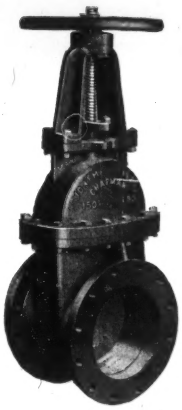

Typical Iron Body Gate Valve, Bronze Mounted, Solid Wedge, Rising Stem, Flanged Ends

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IRON BODY GATE VALVES

Chapman is well equipped to meet all needs of the sewage field for valve equipment of every type. Wide use of Chapman valves in this field is good evidence of the quality and service which may be expected of all Chapman products. Chapman Iron Body Gate Valves have a long and enviable record in sewage applications. The standardized lines include all types and sizes to meet every conceivable need. Selection from Chapman's standardized lines means the best valve which can be produced for the service intended, with maximum service at minimum cost.

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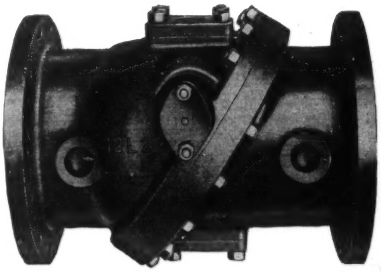
TILTING DISC CHECKS

These check valves, unique in design and operation, are especially adapted to various applications in the sewage works field. Many of the objectionable characteristics of conventional type swing checks have been overcome in the Tilting Disc Check, due to the bell-crank action of the disc and the streamlined waterway. Slamming is eliminated. Excessive wear of moving parts and friction losses are reduced to a minimum. The valve closes drop tight, and is highly efficient and economical.



Chapman Iron Body Non-Slam Tilting Disc Check Valve

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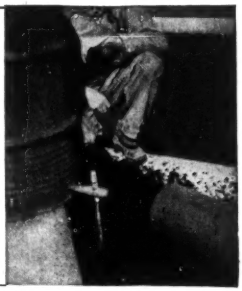
← A portable hand pump.

A discarded drum fitted with a wooden spigot. →



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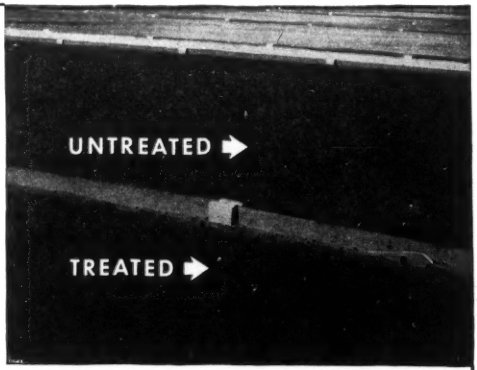

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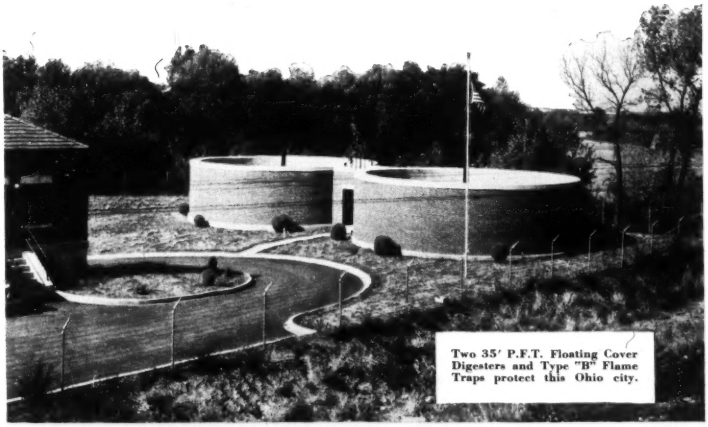

Two 35′ P.F.T. Floating Cover Digesters and Type "B" Flame Traps protect this Ohio city.

P.F.T *Pacific Flush-Tank Co.*

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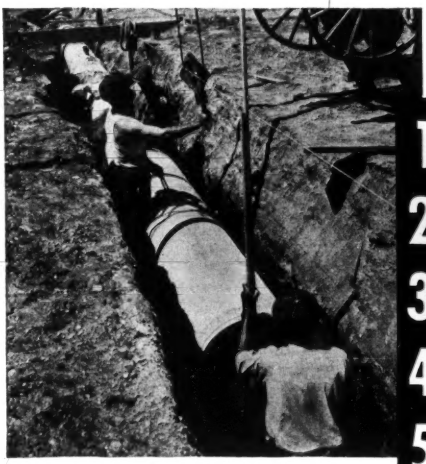
A 5-POINT SAVING IN SEWER-LINE COSTS



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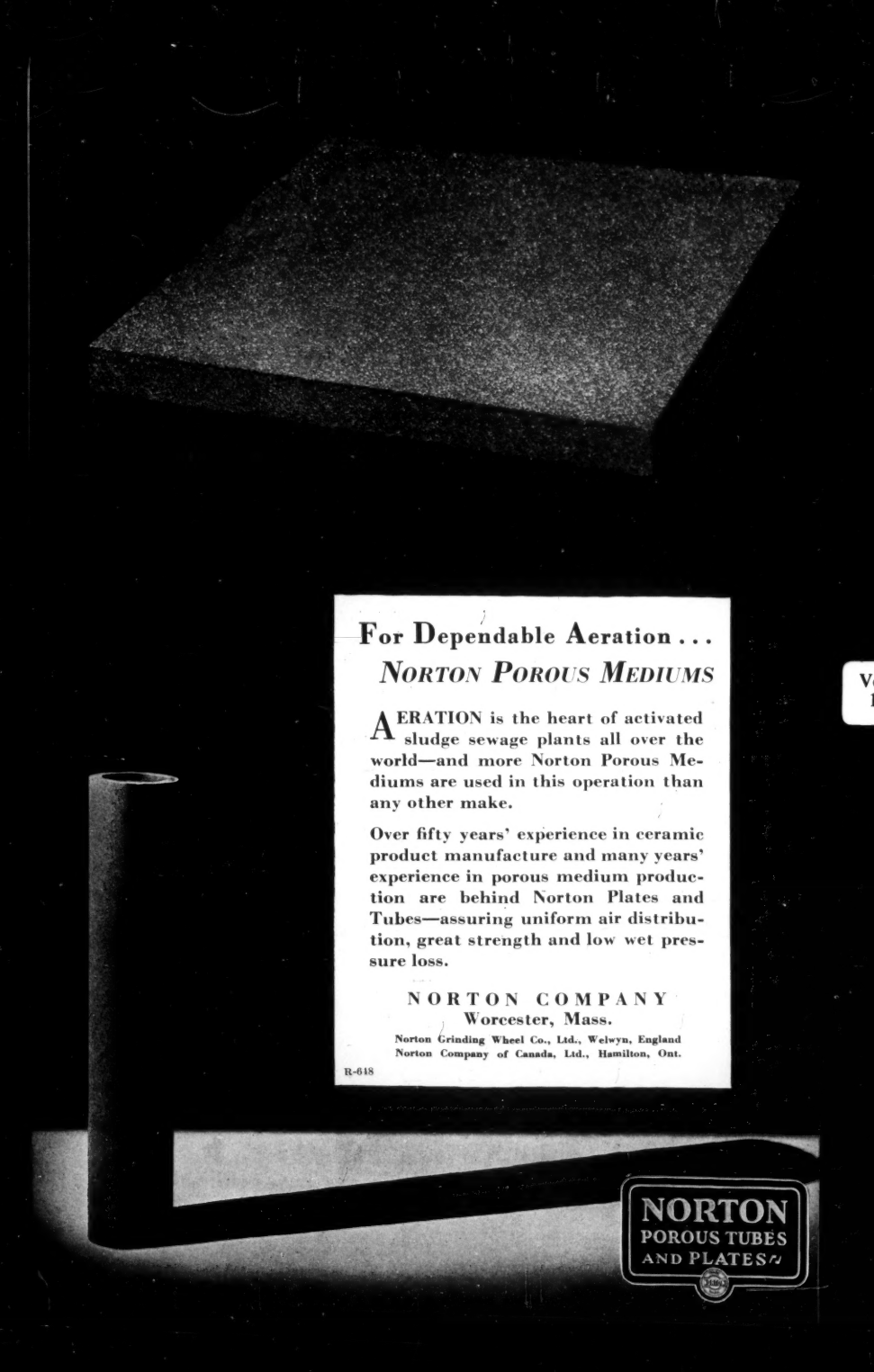
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Sewage Research

EXPERIMENTS WITH HIGH-RATE TRICKLING FILTERS AT BALTIMORE *

By C. E. Keefer and Herman Kratz, Jr.

Bureau of Sewers, Baltimore, Md.

As a consequence of the satisfactory results obtained with high-rate trickling filters by Halvorson, Mohlman and others, a series of field experiments were conducted at the Baltimore sewage plant to confirm the work of these investigators and to obtain additional information regarding this interesting development in sewage treatment. The following were some of the questions that were studied:

1. Can trickling filters be operated at rates varying from about 7 to 10 mil. gal. per acre daily without clogging and with the production of a reasonably satisfactory effluent?
2. What effect has temperature on the operation of high-rate filters?
3. What degree of purification is obtained with various depths of filters when operated at high rates?

Description of Filters and Auxiliary Equipment

A small portion of the 30 acres of filters at the Baltimore plant was used for the experiments. These filters are constructed of trap rock varying in size from 1 to 2½ in. and are 8½ ft. deep. The section of the filters used during the tests has been in continuous service since the latter part of 1911. At the beginning of the experiments the filter stone was in excellent condition with no evidence of clogging. Two 8-arm rotary distributors (Fig. 1), each 47 ft. 6 in. in diameter, were erected on the filter for applying sewage to the stone. Just before the experiments were begun, the nozzles adjacent to the rotary distributors were removed and the flow to these nozzles was shut off. The flow to the distributors was measured by an 8- by 4-in. Venturi-meter tube. The nozzles on the arms of the distributors were made of terra cotta, and had ¾-in., ⅞-in., 1-in., 1⅛-in. and 1¼-in. orifices. The size used depended upon the flow being treated. Both distributors were used at the lower rates of flow and only one at the higher rates. The length of the distributor arms was shortened at the high rates in order not to exceed the capacity of the Venturi tube. Table I gives the areas of the trickling filter used at the various rates of flow.

A portion of one of the filter beds, having an area of 1½ acres, adjacent to the rotary distributors was operated throughout the experiment

* Presented at the Fourteenth Annual Conference of the Maryland-Delaware Water and Sewerage Assn., Salisbury, Md., May 16, 1940.

at an approximate rate of 3 mil. gal. per acre daily. The results obtained were used as a basis of comparison with the performance of the test filter. These beds are provided with Merritt square-spray nozzles, spaced 15 ft. apart. The flow to the beds was continuous. The area covered by the discharge from each nozzle was controlled by an automatically operated butterfly valve in the influent conduit serving the beds.

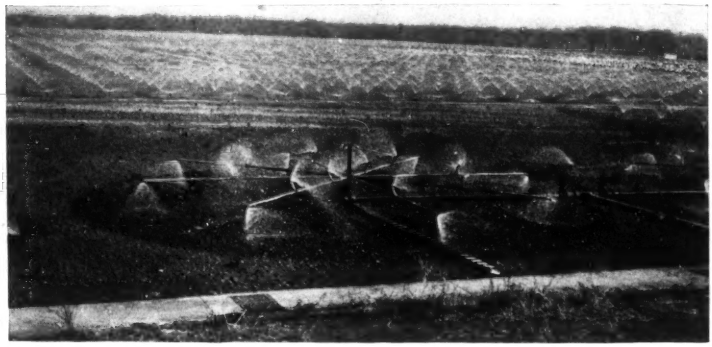

FIG. 1.—Rotary distributor, Baltimore sewage works.

Character of Sewage Treated.—The settled sewage discharging from the rotary distributors was the same as that applied to the remainder of the filters. This sewage had passed through mechanically-cleaned bar screens with ¾-in. clear openings, and had been treated in preliminary-sedimentation tanks with rotary sludge-removal equipment, having an average theoretical detention period of about 2 hr.

TABLE I.—*Areas of Trickling Filter Used with Various Rates of Application of Settled Sewage*

Rate of Application, Mil. Gal. per Acre Daily	Number of Distributors	Total Area, Sq. Ft.
6.5	2	4,580
10.0	1 or 2	2,290 or 4,580
14.0	1	2,290
15.0	1	2,290
18.0	1	1,521
22.0	1	1,521
26.0	1	1,257
30.0	1	1,257

Samples of the influent to and the effluent from the filters were collected every hour, stored on ice, composited for 24 hr. and then analyzed. These composite samples were collected sometimes two but mostly three times each week. The filter effluents were well stirred

just before being analyzed, and did not have the added benefit resulting from sedimentation.

Results Obtained

First Group of Experiments.—The operation of the high-rate trickling filter began on July 6, 1938. After about three weeks of preliminary work, the actual experiments were started on July 28. The first group of tests was continued from then until January 18, 1939. During this period (Table II) the rate of flow was increased from 6.5 to 26.0 mil. gal. per acre daily—generally in increments of 4.0 mil. gal. per acre daily. The average 5-day B.O.D. loading was 784 lb. per acre-foot per day at the low rate of application and 5,149 lb. at the high rate. When the rates of application were 6.5 and 10.0 mil. gal. per acre daily, the 5-day B.O.D. of the effluent was 12.7 and 26.6 p.p.m., respectively. At these rates the effluent had a lower B.O.D. than that of the control filter dosed with 3.0 mil. gal. per acre daily. Only when the rate was 14.0 mil. gal. per acre daily or more was the effluent inferior to that of the control filter. Even when the rate was 26.0 mil. gal. per acre daily, the 5-day B.O.D. was reduced from 201.9 to 102.9 p.p.m., a reduction of 49 per cent. The nitrates in the effluent decreased (Fig. 2) as the rate of application increased. On the other hand the removal of 5-day B.O.D. increased from 703 lb. per acre-foot daily when the rate of application was 6.5 mil. gal. per acre daily to 2,525 lb. (Table II and Fig. 3) with a rate of application of 26.0 mil. gal. During this same period the maximum removal of 5-day B.O.D. by the control filter was 428 lb. per acre-foot daily. The temperature of the influent to the filters gradually decreased from 76° F. in July, 1938, to 56° F. in January, 1939. This decrease is partly responsible for the effluent having a higher B.O.D. as the loading increased.

Second Group of Experiments.—The second group of experiments was begun on February 7, 1939, and continued until July 26, 1939. The rate of application was 6.5 mil. gal. per acre daily at the beginning and was increased in regular increments to 30.0 mil. gal. Even at this maximum rate the 5-day B.O.D. of the sewage was reduced from 155.6 to 44.2 p.p.m. (Table II), a reduction of 71.6 per cent. Figure 3 indicates the amount of 5-day B.O.D. removed per acre-foot per day. A maximum removal of 3,278 lb. per acre-foot daily was obtained when the rate of application was 30.0 mil. gal. per acre daily and the applied 5-day B.O.D. load was 4,579 lb. per acre-foot daily.

During these experiments the rate of application was comparatively low in cold weather and high in hot weather. The temperature conditions were thus the reverse of those which prevailed during the first group of experiments. Figure 2 indicates the pronounced effect that the temperature of the sewage had on the B.O.D. of the effluent. This effect will be considered when the rate of application was 6.5 mil. gal. per acre daily. When the temperature of the sewage was 76° F., the effluent had a 5-day B.O.D. of 12.7 p.p.m., which was 34.1 p.p.m. less than the B.O.D. of the effluent at a temperature of 54° F. On the other

TABLE II.—*Performance of High-Rate Trickling Filter*

Back River Sewage Works, Baltimore, Md.
Depth of filter: 8.5 ft.

Date	Filter Influent			High-Rate Filter								Control Filter							
				Load Applied		Filter Effluent (Not settled)				5-day B.O.D. Removal		Load Applied		Filter Effluent (Not settled)				5-day B.O.D. Removal	
	5-day B.O.D., p.p.m.	NH_3, p.p.m.	Temperature, °F.	Mil. Gal. per Acre Daily	Lb. of 5-day B.O.D. per Acre-ft. Daily	5-day B.O.D., p.p.m.	Nitrogen as NH_3, p.p.m.	Nitrites, p.p.m.	Nitrates, p.p.m.	Per Cent	Lb. per Acre-ft. Daily	Mil. Gal. per Acre Daily	Lb. of 5-day B.O.D. per Acre-ft. Daily	5-day B.O.D., p.p.m.	Nitrogen as NH_3, p.p.m.	Nitrites, p.p.m.	Nitrates, p.p.m.	Per Cent	Lb. per Acre-ft. Daily
First Group of Experiments																			
1938																			
July 28–Aug. 18	122.9	18.6	76	6.5	784	12.7	8.5	0.213	12.3	89.7	703	3.0	362	24.5	9.8	0.229	10.6	80.1	290
Aug. 25–Sept. 16	160.1	21.2	75	10.0	1,570	26.6	14.9	0.202	7.1	83.4	1,309	3.0	471	27.2	12.4	0.219	9.6	83.0	391
Sept. 27–Oct. 13	162.0	21.3	70	14.0	2,225	34.3	18.0	0.186	3.1	78.8	1,754	3.0	477	31.1	12.9	0.271	9.6	80.8	385
Oct. 25–Nov. 13	171.0	22.0	67	18.0	3,019	41.7	21.2	0.104	1.4	75.6	2,283	3.0	503	32.7	12.3	0.258	9.7	80.9	407
Nov. 22–Dec. 13	201.4	21.2	60	22.0	4,346	89.4	20.1	0.103	0.78	55.6	2,417	3.0	593	56.0	15.8	0.281	7.4	72.2	428
1939																			
Jan. 3–18	201.9	20.5	56	26.0	5,149	102.9	20.5	0.144	0.35	49.0	2,525	3.0	594	64.9	14.9	0.530	7.0	67.9	403
Second Group of Experiments																			
1939																			
Feb. 7–28	161.4	18.2	54	6.5	1,029	46.8	14.0	0.494	5.7	71.0	731	3.0	475	40.1	12.3	0.398	8.0	75.2	357
Mch. 3–21	158.8	18.9	55	10.0	1,558	43.5	15.9	0.483	2.9	72.6	1,131	3.0	467	35.4	13.5	0.389	9.4	77.7	363
Mch. 26–Apr. 19	157.1	20.4	57	14.0	2,157	43.7	19.8	0.214	1.0	72.2	1,557	3.0	462	33.4	14.5	0.339	9.4	78.7	364
Apr. 25–May 17	154.3	21.1	63	18.0	2,724	40.0	21.1	0.110	1.2	74.1	2,018	3.0	454	29.2	15.8	0.265	10.3	81.1	368
May 21–June 9	155.9	20.8	70	22.0	3,364	41.3	21.3	0.095	1.1	73.5	2,473	3.0	459	24.9	12.7	0.244	10.8	84.0	386
June 13–25	138.6	21.2	72	26.0	3,535	37.8	21.2	0.086	1.0	72.7	2,571	3.0	408	23.2	12.1	0.324	12.0	83.3	340
July 6–26	155.6	...	75	30.0	4,579	44.2	...	...	...	71.6	3,278	3.0	458	26.2	...	...	...	83.2	381

hand when the rate of application was 26 mil. gal. per acre daily, the effluent at a temperature of 56° F. had a 5-day B.O.D. of 102.9 p.p.m., which was 65.1 p.p.m. higher than the B.O.D. of the effluent at a temperature of 72° F. As would be expected, low temperatures had a much more deleterious effect on the degree of purification obtained when the rate of application was 26 mil. gal. per acre daily than when the

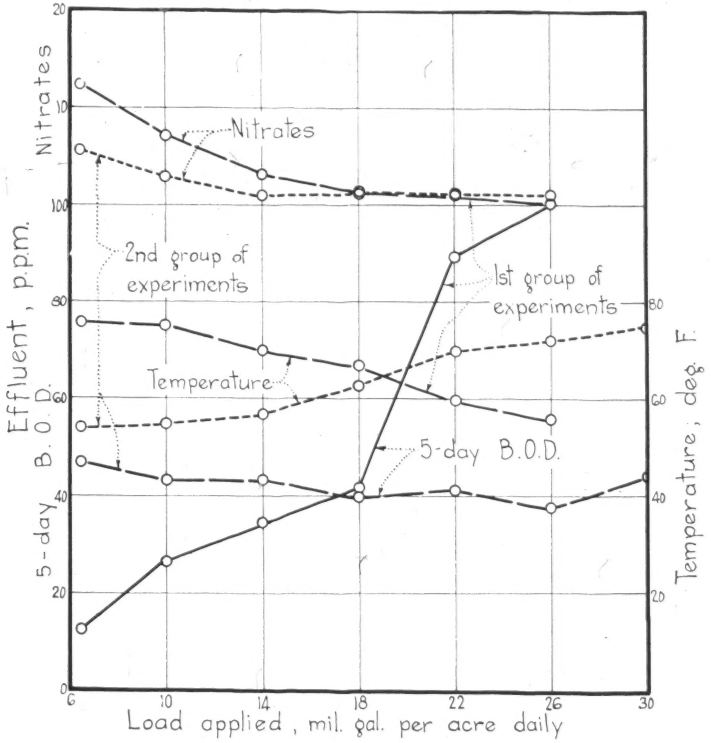

FIG. 2.—Performance of high-rate trickling filter.

rate was 6.5 mil. gal. Table II indicates the important part that temperature plays in the functioning of trickling filters. A better effluent was obtained when the rate of application was 30.0 mil. gal. per acre daily and the temperature of the sewage was 75° F. than when the rate was 6.5 mil. gal. and the temperature was 54° F.

Third Group of Experiments.—During the third group of experiments the sewage was applied at a uniform and high rate for several

weeks. For six weeks from August 23, 1939, to October 4, 1939, the rate of application was 10.0 mil. gal. per acre daily. One reason for using this rate was that Halvorson, Savage and Piret (1) reported poor results at this rate. From October 11, 1939, to November 15, 1939, the

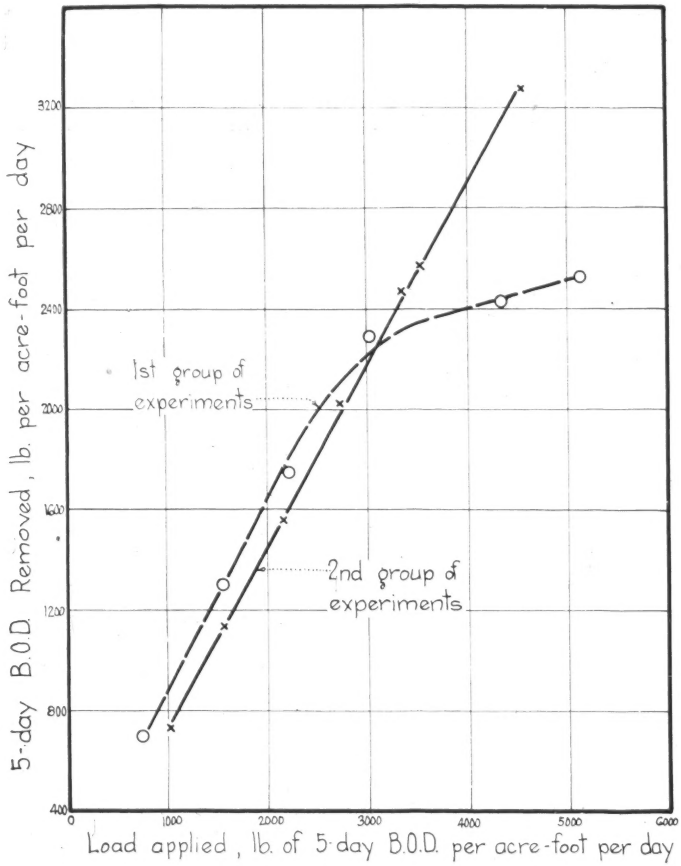

FIG. 3.—Removal of 5-day B.O.D. by high-rate trickling filters.

rate was increased to 15.0 mil. gal. per acre daily. In addition to analyzing the effluent, samples were collected at depths of 2, 4, and 6 ft. from the top of the filter. The results of the studies are given in Table III and Fig. 4. When the rate of flow was 10.0 mil. gal. per acre daily

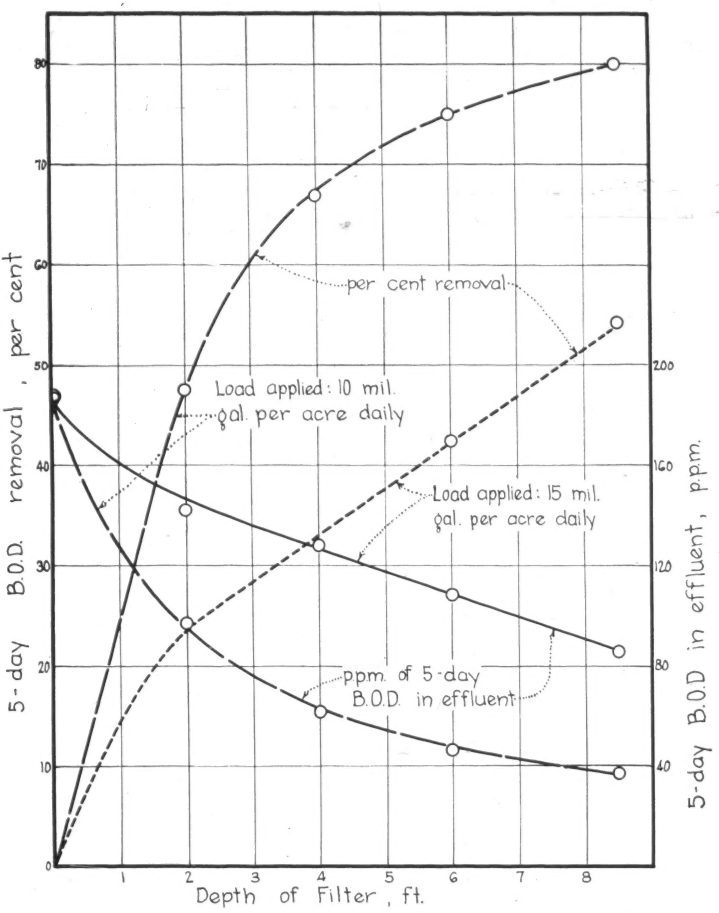

FIG. 4.—Character of effluent at various depths from high-rate trickling filters.

the removal of 5-day B.O.D. after passing through the top 2 ft. of stone was 47.5 per cent. A removal of 66.8 per cent was obtained by passing the sewage through 4 ft. of stone, and 80.0 per cent by the entire filter (8.5 ft.). At a rate of 15.0 mil. gal. per acre daily the removal of B.O.D. was considerably less than at 10.0 mil. gal.

During the entire experiment there was no ponding of sewage at any of the rates of flow. The appearance of the stones on the surface of the filter was about the same as the control filter.

TABLE III.—*Removal of 5-Day B.O.D. by High-Rate Trickling Filter at Various Depths Below Top of Filter, Back River Sewage Works, Baltimore, Md.*

Date	Filter Influent		Load Applied		5-day B.O.D. of Effluent (Not settled)							
					2 ft. from Top		4 ft. from Top		6 ft. from Top		8.5 ft. from Top (Final Effluent)	
	5-day B.O.D., p.p.m.	Temperature, °F.	Mil. Gal. per Acre Daily	Lb. of 5-day B.O.D.	p.p.m.	Per Cent Removal	p.p.m.	Per Cent Removal	p.p.m.	Per Cent Removal	p.p.m.	Per Cent Removal
1939												
Aug. 23–Oct. 4.	184.6	78	10.0	1,811	97.0	47.5	61.3	66.8	45.8	75.2	36.9	80.0
Oct. 11–Nov. 15	187.0	68	15.0	2,752	142.3	23.9	127.3	31.9	108.0	42.2	85.3	54.4

CONCLUSIONS

It seems justifiable to draw the following conclusions, which apply particularly to the filters in Baltimore, as a result of the experiments:

1. There is no reason to believe that ponding will occur at any rate of flow from 6.5 to 30 mil. gal. per acre daily.

2. As the rate of flow increases, a gradual increase in the B.O.D. of the effluent and a decrease in nitrification can be expected. This decrease in B.O.D. removal was not marked even when the flow was 10.0 mil. gal. per acre daily.

3. Even at high rates of application (26 mil. gal. per acre daily) a reduction of approximately 50 per cent of the B.O.D. of the influent to the filter can be expected in winter and 70 per cent or more in summer.

4. A considerable portion of the B.O.D. can be removed in summer by shallow filters varying from 2 to 4 ft. deep when the rate is as high as 10 mil. gal. per acre daily. The removal would undoubtedly be less in winter.

5. If an effluent is to be better than that from sedimentation tanks and inferior to that from a low-rate trickling filter, a high-rate filter may serve. Treatment comparable to chemical precipitation or sedimentation and magnetite filters can be obtained by sedimentation and high-rate trickling filters. The degree of treatment depends upon the rate of applying the sewage and the depth of the filters.

The sewage-treatment works are under the general supervision of George Cobb, chief engineer, Department of Public Works, and G. E. Finck, sewerage engineer, with G. K. Armeling, superintendent of the plant. Acknowledgments are due the Red Wing Sewer Pipe Corporation, who furnished the rotary distributors. J. W. Bushman, junior chemist, assisted in conducting the experiments and in making the chemical analyses.

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1. H. O. Halvorson, G. M. Savage and E. L. Piret, "Some Fundamental Factors Concerned in the Operation of Trickling Filters." THIS JOURNAL, **8**, 888 (1936).

STUDIES OF SEWAGE PURIFICATION

XII. METABOLISM OF GLUCOSE BY ACTIVATED SLUDGE

By C. C. Ruchhoft,[1] J. F. Kachmar,[2] and O. R. Placak[3]

[1] *Principal Chemist,* [2] *Jr. Chemist, and* [3] *Jr. Chemist, United States Public Health Service, Stream Pollution Investigation Station, Cincinnati, Ohio*

The factors involved in the removal of glucose from substrates by activated sludge were studied in the previous paper of this series.[1] It was shown that the rate of glucose removal was a function of the quantity of activated sludge present. Factors influencing the rate of glucose removal and indicating the biochemical nature of the reaction were: the necessity for the maintenance of dissovled oxygen and the control of both temperature and pH within common biological ranges. The fact that supplemental feeding of organic nitrogen promoted glucose removal, that starvation by prolonged aeration without food destroyed glucose removal ability and that a sludge could be acclimated by repeated glucose feeding indicated further the biochemical character of the glucose removal reaction. Ingols'[2] experiments also favor the view that the removal of glucose from solution is a biological reaction. The review in Paper XI [1] indicated the lack of knowledge of the glucose removal mechanism and the desirability of such knowledge for the better understanding and operation of the activated sludge process.

It is the purpose of this paper to present the results of a study of glucose metabolism by activated sludge. While bacterial metabolism of glucose is generally considered to be largely dissimilation, Clifton and Logan[3] have shown that suspensions and cultures of Esch. coli also assimilate glucose. Both the dissimilative and assimilative mechanisms of glucose metabolism by activated sludge have been considered. The quantities of oxygen utilized, percentages of glucose oxidized and respiratory quotients during glucose removal have been determined. A search for dissimilation products of glucose has been made and the assimilation of a considerable quantity of the glucose removed from solution has been demonstrated. This assimilative mechanism of the bacterial flocs of activated sludge is suggested as an explanation for the large increase in quantity of activated sludge produced as a result of carbohydrate feeding, which is often followed by sludge bulking.

Oxygen Relationships During Glucose Removal by Activated Sludge

Oxygen utilization during glucose removal by activated sludge was determined by the method described in an earlier paper.[4] The quantities of oxygen used in the glucose fed sludge and in the control sludge were determined simultaneously during aeration. The quantity of oxygen utilized as a result of the attack and removal of glucose is taken as the increment of oxygen absorbed by the glucose fed sludge. All of the experiments to be described were carried out in 20° C. incubators

and the analytical methods employed were the same as in the previous paper.[1] The oxygen utilization and glucose removal data for a typical experiment in which glucose alone was fed are given in Table I. The quantities of oxygen used by the glucose fed and control sludges are given in Columns 1 and 2, respectively. The increments of oxygen used in the attack upon glucose are given in Column 3 and the quantities of glucose removed from solution in Column 4. The quantities of oxygen that would have been required for the complete combustion of the glucose removed were calculated. These values, which are the "*L* values" or total carbonaceous oxygen demands of the glucose that had been removed at each observation time, are given in Column 5. The percentages of these total carbonaceous oxygen demand values of glucose removed which had been satisfied (oxidized) were calculated and

TABLE I.—*Removal and Oxidation of Glucose by Activated Sludge*

Aeration Time, Hours	Oxygen Utilized, P.p.m.			Glucose Removed from Solution by Sludge, P.p.m.	O_2 Required (P.p.m.) for Complete Oxidation of Glucose Removed	Percentage Oxidation of Glucose Removed	Maximum Possible Percentage Oxidation of Glucose by All O_2 Used in Fed Sludge
	Sludge plus Glucose	Sludge Control	As a Result of Glucose Added				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
½	26.2	9.0	17.2	172.0	184.0	9.3	14.24
1	51.8	17.5	34.3	306.0	326.0	10.5	15.87
1½	62.4	25.0	37.4	406.0	433.0	8.6	14.41
2	85.7	32.6	53.1	471.0	503.0	10.6	17.03
3	103.0	42.8	60.2	660.0	704.0	8.6	14.63
5	125.0	50.0	75.0	895.0	955.0	7.9	13.08
23	247.7	139.9	107.8	896.0	956.0	11.3	25.91

Derivation of data:
(3) = (1) − (2).
(5) = (4) × 1.067.
(6) = (3) × 100 ÷ (5).
(7) = (1) × 100 ÷ (5).

are given in Column 6. The maximum possible percentage of oxidation of glucose, if all of the oxygen utilized by the fed sludge mixtures is attributed to glucose oxidation, is given in Column 7. These data indicate that only about 11.3 per cent of the glucose was oxidized during the 23-hour aeration period in which 896 p.p.m. of glucose were removed from solution. It is noted also that during this removal reaction the fraction of glucose oxidized changes but slightly so that errors in the determinations somewhat obscure the trend.

In some experiments the plant activated sludge was acclimated to glucose by dosing the sludge daily (in the laboratory for a few days) with sewage containing 500 p.p.m. of glucose. When such sludge was dosed with 1000 p.p.m. of glucose the sugar was largely removed from solution in the first one and one-half hour aeration period. It may be assumed that the low oxidation of glucose found in the experiment in

which glucose only was fed, was the result of insufficient nitrogen for metabolic uses of the cell. Carpenter [5] has recently shown that the ratio of glucose to non-protein nitrogen used during glucose utilization by the coliform group was about 48 to 1. Assuming that this ratio would also apply to the organisms in activated sludge, about 100 p.p.m. of glycine as a non-protein source of nitrogen was added with 1000 p.p.m. of glucose in a number of experiments. The oxygen utilization and glucose removal data for one of these experiments are given in Table II. The percentage oxidation data in Tables I and II are similar. However, the trend toward slightly higher percentage oxidation with increasing time is more evident in Table II where this percentage increased from 7.0 at 1½ hours to 16.8 in 24 hours. Continuation of the sludge aeration to 40 hours in this experiment did not increase ap-

TABLE II.—*Removal and Oxidation of Glucose by Activated Sludge*

(1100 p.p.m. of Glucose Fed to a Plant Sludge that Had Been Glucose Acclimated)

Aeration Time, Hours	Oxygen Utilized, P.p.m.			Glucose Removed from Solution by Sludge, P.p.m.	O_2 Required (P.p.m.) for Complete Oxidation of Glucose Removed	Percentage Oxidation of Glucose Removed	Maximum Possible Percentage Oxidation of Glucose by All O_2 Used in Fed Sludge
	Sludge plus Glucose	Sludge Control	As a Result of Glucose Added				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
1½	107.0	26.6	80.4	1072.0	1144.0	7.0	9.3
3	146.4	43.1	103.3	1099.0	1172.0	8.8	12.5
4½	168.6	58.0	110.6	1100.0	1174.0	9.4	14.4
6	187.0	76.6	110.4	1100.0	1174.0	9.4	15.9
24	322.7	125.6	197.1	1100.0	1174.0	16.8	27.5
40	344.1	146.0	198.1	1100.0	1174.0	16.9	29.3

Derivation of Data:

(3) = (1) − (2). (6) = (3) × 100 ÷ (5).

(5) = (4) × 1.067. (7) = (1) × 100 ÷ (5).

preciably the percentage of glucose oxidized. Additional experiments were run with and without supplemental nitrogen from which it is concluded that the addition of organic nitrogen with a single dose of 1000 p.p.m. of glucose to our activated sludge had little if any effect upon the percentage of glucose oxidized.

Glucose oxidation experiments were also carried out on various activated sludge samples using doses of 400 to 5155 p.p.m. of glucose. The percentage oxidation of glucose obtained after various aeration periods in each of fifteen experiments of this kind is given in Table III. These data indicate that the quality of the sludge used and the quantity of glucose added affect the oxidation percentage of glucose removed from solution during the first few hours of the aeration period. If a dose of glucose up to 500 p.p.m. is added to a sludge which removes glu-

cose at a very low rate, as illustrated in Experiments 70 and 74, the indications are that a high percentage of the glucose removed may be oxidized in the first 1½ hour period. Thereafter the percentage oxidized falls for several hours and, after the glucose has all been removed from solution, slowly rises again. The sludge in Experiment 70 re-

TABLE III.—*Summary of Results of Percentage Oxidation of Glucose Removed from Solution by Activated Sludge*
All Experiments Conducted at 20° C.

Classification of Sludge on Basis of Its Glucose Removal Ability	Experiment No.	Initial pH of Fed Sludge	Quantity of Suspended Sludge Solids at Start P.p.m.	Feed Added		Percentage of Glucose Dose Removed During First 1½ Hrs. of Aeration	Percentage Oxidation of Glucose Removed in Indicated Time in Hours			
				Glucose, P.p.m.	Supplemental Nitrogen		1½	3	4½	23 or 24
Poor	70	7.0	3422	405	None	10.3	75.6	23.9	31.9	—
Poor	74	6.7	1991	503	None	9.4	49.8	16.8	13.7	20.0
Normal	10	—	1940	1000	None	40.6	8.6	8.6	7.9*	11.3
Normal	55	6.6	2856	1025	None	10.0	4.5	12.4	9.6	21.2
Normal	56	6.3	1640	997	None	22.7	8.9	9.7	8.8	13.5
Normal	58	7.3	3104	957	None	14.8	—	5.9	4.8	14.8
Normal	59	6.9	4448	1090	Glycine 100 p.p.m.	34.8	8.2	11.4	15.8	—
Normal	72	6.4	3128	1039	None	27.7	12.0	12.1	9.8	12.5
Normal	64	—	2720	470	None	26.6	11.5	10.2	14.8	21.1
Normal	75	7.2	2522	395	None	59.6	10.3	8.6	13.3	17.3
Normal	79	7.4	3150	935	None	15.4	24.0	24.6	25.9	31.8
Glucose acclimated	62	7.0	2056	1108	Glycine 100 p.p.m.	97.0	7.0	8.8	9.4	16.8
Glucose acclimated	65	7.5	2334	1127	Glycine 100 p.p.m.	96.8	5.2	7.9	10.2	18.3
Glucose acclimated	69	7.2	2131	5155	1000 p.p.m. urea	14.0	11.5	11.3	11.6	—
Glucose acclimated	76	7.3	2286	402	None	99.7	13.0	14.4	14.7	16.8
Combined average for normal and glucose acclimated sludges							10.4	11.2	12.0	17.8

* 5 Hours.

moved glucose very poorly during the first 1½ hour aeration period, but in other respects this sludge appeared normal. The sludge in Experiment 74 was the only bulking sludge used in these experiments. This sludge contained large quantities of *Sphaerotilus natans* and the sludge index (volume in ml. containing one gram of sludge after 30

minute settlement) was 182. The glucose removal and oxidation characteristics of pure cultures of *Sphaerotilus natans* will be discussed in a later paper.

Data obtained in nine experiments with normal sludge are given in the middle section of Table III. These experiments indicate the tendency of the percentage of glucose removed that is oxidized to increase slowly during the aeration period. The mean percentages of glucose oxidized for these experiments are 11.0, 11.5, 12.3, and 17.9 for the 1½, 3, 4½ and 23-hour aeration periods, respectively. The data obtained with glucose acclimated sludge in Experiments 62, 65, 69 and 76 are given in the lower section of this table. The column of this table giving the percentage of glucose removed from solution shows over 95 per cent glucose removal in three of these experiments in the first hour and one-half. In Experiment 69, 5155 p.p.m. of glucose were fed to a sludge containing 2131 p.p.m. of suspended solids and even with this extremely high dose 14 per cent or 722 p.p.m. were removed from solution in an

TABLE IV.—*Comparison of Percentage Oxidation of Glucose by Several Bacterial Agents After Various Periods of Aeration*

Bacterial Agent	Percentage Oxidation of Glucose Removed in Indicated Time in Hours				
	1½	3	4½	10	24
Normal activated sludge	11.0	11.5	12.3		17.9
Pure culture zoogleal sludge*	31.0	33.1	33.5		45.1
Bact. coli culture	—	21.6	—	28.1	30.6
Bact. aerogenes culture	—	13.1	—	31.7	44.6

* Mean of seven experiments employing two zoogleal strains.

hour and one-half. The percentages of glucose oxidized with the glucose acclimated activated sludge were very similar to the values for normal sludge.

These values for percentage oxidation of the glucose removed are surprisingly low in view of the velocity of the removal reaction and the belief expressed by Eldridge and Robinson[6] that carbohydrates are completely oxidized to CO_2 and H_2O by biochemical oxidation in the activated sludge process. Consequently, experiments similar to the above were carried out with several other bacterial agents capable of attacking glucose. The results obtained are summarized in Table IV and indicate that plant activated sludge oxidized a smaller percentage of the removed glucose than did the other agents used.

The percentage oxidation of glucose removed by activated sludge is equivalent to the percentage of the total carbonaceous oxygen demand reduction of a sewage substrate that is actually oxidized under aeration with a non-nitrifying activated sludge as given in an earlier paper.[7] Consequently, a comparison of these values is made below:

Substrate	Percentage of L Value Reduction that is Actually Oxidized in Indicated Time in Hours				
	$1\frac{1}{2}$	3	$4\frac{1}{2}$ or 5	10	24
Domestic Sewage	21.9	31.6	37.9	48.4	57.6
Glucose	11.0	11.5	12.3	—	17.9

These data indicate a very decided difference in the metabolism of glucose and of sewage by activated sludge. The percentage of the substrate oxidized is much lower for this easily attacked carbohydrate than for sewage. Consequently, a much higher percentage of the glucose removed must be credited to adsorption and assimilation or synthesis.

An experiment which illustrates the difference in the disposal mechanism of glucose and peptone was carried out. In this experiment an 8 liter sample of plant sludge, upon its removal from the plant, was dosed with 500 p.p.m. of peptone, and the oxidation as a result of this feed was determined on portions of this sludge. Upon the second day 1039 p.p.m. of glucose were added to the sludge remaining after 1 liter was taken for a control and the oxidation resulting from the glucose dose was determined. Upon the third day 500 p.p.m. of peptone were again fed and the oxygen utilization of the control and fed portions was again determined. The results are given in Table V and it is notice-

TABLE V.—*Comparison of the Oxidation of Peptone and Glucose by Activated Sludge upon Successive Days*

Aeration Time, Hours	Oxygen Utilized, P.p.m.			Total B.O.D. of Substrate Feed Removed	Percentage Oxidation of Substrate Removed
	Sludge Plus Feed	Sludge Control	As a Result of Feed		
First Day Feed 500 P.p.m. Peptone					
$1\frac{1}{2}$	72.7	21.1	51.6	207.0	24.9
3	116.4	37.6	78.8	255.0	30.9
$4\frac{1}{2}$	153.2	47.7	105.5	289.0	36.5
22	402.7	126.8	275.9	537.0	51.4
Second Day Feed 1039 P.p.m. Glucose					
$1\frac{1}{2}$	47.1	10.3	36.8	307.0	12.0
3	86.3	18.8	67.5	557.0	12.1
$4\frac{1}{2}$	112.0	34.3	77.7	790.0	9.8
$5\frac{1}{2}$	134.0	46.8	87.2	955.0	9.1
22	271.9	134.4	137.5	1096.0	12.5
Third Day Feed 500 P.p.m. Peptone					
$1\frac{1}{2}$	81.6	19.2	62.4	207.0	30.1
3	115.9	31.0	84.9	255.0	33.3
$4\frac{1}{2}$	158.6	34.5	124.1	289.0	42.9
$5\frac{1}{2}$	185.7	39.7	146.0	312.0	46.7
22	414.7	128.3	286.8	537.0	53.4

able that the oxygen utilization of the control sludge was very similar during the three successive tests. While the oxygen utilization results of the sludge fed with 500 p.p.m. of peptone upon the first and third day were very similar, these results were much greater than the quantities of oxygen utilized by the sludge fed with 1039 p.p.m. of glucose on the intervening day. It is strikingly shown that while larger quantities of glucose than peptone were removed from solution by activated sludge in this experiment, much less oxygen was used during the glucose removal than during peptone removal. Thus while only about 12 per cent of the glucose removed from solution was oxidized in 22 hours by activated sludge, over 50 per cent of the peptone removed was oxi-

TABLE VI.—*Quantities of Oxygen Utilized to Oxidize Substrate by Activated Sludge Under Aeration*

Description of Treatment of Sludge	Initial Normal Sludge Taken from Plant		Portion A After Dosing Daily With Sewage for 9 Days		Portion A After Dosing Daily with Same Sewage Fortified with 500 P.p.m. of Glucose for 7 Days	
Oxidation Tests upon Portions Treated as Above	A		B		C	
Feed Added	Oxygen Utilized as a Result of the Addition of the Feed, P.p.m.					
	Sewage	Sewage plus Glucose	Sewage	Sewage plus Glucose	Sewage	Sewage plus Glucose
Aeration Time, Hr.						
½	21.6	19.0	9.8	14.3	40.1	32.4
1	30.3	26.8	25.9	28.3	42.7	40.2
3	65.0	64.5	81.6	109.9	65.6	59.0
5	90.2	96.9	123.4	154.5	79.1	79.8
23	—	—	324.2	325.3	116.6	117.9

dized during the same aeration time. The experiment also showed no detriment to the peptone oxidizing ability of the sludge by the intervening treatment with 1000 p.p.m. of glucose. These data again illustrate the difference in the glucose metabolism over that of peptone and sewage.

Another experiment was performed which showed that when activated sludge was dosed with sewage plus glucose very little more oxygen was utilized than when sewage was added alone. Table VI is self-explanatory and presents the data obtained. In each case the quantities of oxygen utilized as a result of the addition of the feed were obtained by subtracting the quantities of oxygen used by the control sludge portions from the quantities used by the portions fed with sewage

and with sewage plus 500 p.p.m. of glucose. It will be noted that 500 p.p.m. of glucose has an oxygen demand L value of 534 p.p.m. and consequently practically doubles the total carbonaceous oxygen demand of the substrate feed when it is added to domestic sewage. Nevertheless, the addition of this carbohydrate load to the sewage did not increase the oxygen utilization appreciably. In fact, the corresponding oxygen utilization figures for the sewage and sewage plus glucose substrates are all within the limits of error of the determinations with the exception of the 3 and 5-hour observation results upon the B portions. Very little more oxygen is needed when 500 p.p.m. of glucose are added to sewage even though all of the glucose is removed during the aeration period.

It might be assumed that because little additional oxygen is used when glucose is added with sewage to activated sludge that the short time oxygen requirement of the sludge would increase rapidly. The quantities of oxygen in mg. used per gram of dry sludge in the control portions of A, B and C of the above experiment are as follows for the indicated aeration times:

Aeration Time, Hours	Mg. O_2 Used per Gram Sludge		
	A	B	C
½	1.13	2.88	3.42
1	3.03	6.25	9.43
3	9.47	10.28	11.75
5	10.76	10.48	14.80

These results show that the seven repeated treatments with sewage containing 500 p.p.m. of glucose, which sludge portion C received, increased its short-time oxygen demand somewhat over the initial sludge and over the sewage dosed portion B. However, in a sludge overloading experiment previously described,[8] it was indicated that 5-hour sludge demands of 20 mg. of oxygen per gram were perfectly satisfactory. In the above case 5-hour sludge demands of 62.8 mg. of oxygen per gram were obtained when the sludge was badly overloaded. From this it is concluded that dosing sewage containing 500 p.p.m. of glucose daily to activated sludge for 7 days did not produce an overloaded or inferior sludge upon the basis of short-time oxygen demand.

Dissimilation Products of Glucose Metabolism

In several experiments the carbon dioxide produced was determined simultaneously with the oxygen used in both control and glucose fed sludge mixtures. These experiments gave respiratory quotients of 0.89 to 1.15 for glucose-acclimated activated sludge alone and 1.08 to 1.17 for activated sludge-glucose mixtures. These values are in conformity with the respiratory quotient data of Sawyer and Nichols[9]

upon activated sludge and activated sludge-sewage mixtures. When the carbon dioxide produced as a result of the glucose feed was estimated by the difference method, which has been used for determining the oxygen used to oxidize glucose, the respiratory quotient obtained for the glucose metabolized during a 4½ hour aeration period was 1.04. This is within the experimental error that might be expected of the theoretical respiratory quotient of 1.0 for carbohydrate metabolism. The dissimilation product carbon dioxide obtained in these experiments checks the oxidation data and on the average accounts for only about 17 per cent of the glucose removed in a 24-hour aeration period. This immediately raises the question of the exact disposition of the large portion of glucose that has been removed from solution but is not accounted for by complete oxidation. The final experiment in the previous section indicated indirectly that little if any of the balance of the glucose remains adsorbed upon the surfaces of the sludge floc. For if much glucose remained in this way the short time sludge demand would certainly increase rapidly with repeated dosing.

A direct experiment to determine whether glucose remains adsorbed upon the surfaces of the floc was also performed by attempting to recover glucose from sludge in which glucose removal from solution had just been completed. Such a sludge was separated from the supernatant liquor, which contained only 6.0 p.p.m. of glucose, by centrifuging. The separated solids were re-suspended in a quantity of distilled water of the same volume as the supernatant removed. The re-suspended sludge was boiled for 30 minutes under a reflux condenser and the reducing extracts were determined and calculated in terms of glucose. The results in p.p.m. of glucose obtained are shown below:

Glucose Acclimated Sludge 3 Hours after Receiving 1100 P.p.m. of Glucose	Glucose Acclimated Sludge 4½ Hours after Receiving 1100 P.p.m. of Glucose	Plant Sludge Which Never Had Been Dosed with Glucose
43.3	45.2	58.0

This experiment shows conclusively that the glucose removed from solution is not simply adsorbed upon the surfaces of the sludge floc. At the 3-hour point in this experiment the sludge had just completed the removal of 1100 p.p.m. of glucose from the supernatant. The oxygen utilization results have indicated that only about 10 per cent of this glucose was oxidized and yet less than 5 per cent of the original dose was recovered by extraction with boiling distilled water. The experiment also showed that it was possible to extract as much reducing organic matter from the plant activated sludge as from this glucose fed activated sludge immediately after the completion of the glucose removal reaction. When the sludges in the above experiment were extracted with boiling hydrochloric acid solution, more reducing material was recovered from the glucose fed sludge than from the plant sludge.

This seems to indicate that the sludge which had removed the glucose contained a larger quantity of a higher non-reducing carbohydrate which was hydrolyzed by the boiling acid solution. Even after 30 minute treatment with boiling hydrochloric acid solution, however, less than 20 per cent of glucose equivalent of the original dose could be recovered three hours after the glucose was fed. This indicates that a large proportion of the glucose removed from solution is quickly transformed in the bacterial cell to other materials, possibly higher carbohydrates or fats.

It might be assumed that glucose dissimilation of one of the types described by Thaysen and Galloway [10] was produced by activated sludge in which soluble, volatile organic acids are end products. Smit [11] states that such products could not be found and our efforts to recover volatile organic acids from glucose fed sludge were also unsuccessful.

Experiments in which glucose removal and total B.O.D. removal were followed simultaneously gave interesting results. In these experiments the 3, 5 and 7-day B.O.D. of the supernatant of the sludge was determined initially and 1½, 3, 4½ and 23 hours after glucose feeding. A mean L value or total carbonaceous oxygen demand was calculated from the 3, 5, and 7-day B.O.D. results at each observation time and from these data the percentage of the L value removed at each time was calculated. Below, these percentages of the L value removed are compared to the percentages of glucose removal obtained from glucose determinations:

Aeration Time, Hours	1½	3	4½	23
Percentage of L value removed.....	66.6	96.4	97.5	98.8
Percentage of glucose removed.....	68.7	98.9	98.9	98.9

It will be noted that the greatest difference between the percentage of glucose and of total B.O.D. removed was 2.5 at 3 hours. As about 1000 p.p.m. of glucose were fed, the maximum quantity of soluble organic products that might have been formed in this experiment would be equivalent to 25 p.p.m. of glucose. This indicates that if such products are formed they are formed in only extremely minute quantities compared to the quantities of these products formed by the common fermentation processes. For practical purposes it may be considered that the B.O.D. removal of glucose parallels and is equivalent to the glucose removal by activated sludge under aeration. This means that in this process any volatile soluble organic products formed from glucose are either retained by the sludge and are not discharged into the supernatant or that no such products are formed. If volatile organic acids were formed in any quantity and retained by the sludge they would be indicated by a drop in pH and they could be recovered from the sludge by steam distillation. As significant pH drops are not obtained after glucose feeding and volatile acids cannot be recovered by

steam distillation, it must be concluded that such products are not formed to any significant extent during the removal and metabolism of glucose by activated sludge.

Increase in Activated Sludge Solids as a Measure of Glucose Assimilation

As only a small portion of the glucose is oxidized and practically no soluble organic compounds are produced during glucose removal by activated sludge, a very significant increase in sludge solids would be expected. Mention was made in Paper XI[1] of significant increases in sludge solids during glucose feeding. Because of sampling difficulties and errors, special care must be exerted in studying sludge production during glucose feeding. Activated sludge is a biological material in which the basal metabolism continues and the weight of sludge decreases under aeration when it is not fed. Consequently, it is necessary to follow the weight changes in a control sludge and a glucose fed sludge in studying sludge production during the glucose removal reaction. In our experiments to determine sludge production, three or four replicate 25 ml. portions of the control and fed sludge liquors were removed and filtered through prepared Gooch crucibles at each observation time. By this means fairly accurate data upon the changes in sludge solids were obtained. In order to reduce the number of samples that needed to be filtered and weighed during a test, factors for converting the oxygen used by the control sludge to solids lost by oxidation were determined. These factors were obtained by observing the oxygen utilized and the suspended sludge solids remaining simultaneously at intervals during aeration of a number of samples of control activated sludge. The mean ratio of sludge solids lost in milligrams per milligram of oxygen used was 1.12. In estimating the activated sludge solids remaining at any time in the control bottles, the quantity of oxygen used to that time was multiplied by the above factor and the result was subtracted from the initial value for suspended solids. Because of the small loss of solids during short aeration periods in control sludge and the fact that the oxygen utilized data must be obtained in any case, it was preferable to calculate the solids burned in this way rather than to make additional numbers of suspended solid determinations upon the control sludge for each experiment.

The data obtained in a study of the production of sludge from glucose by aeration with normal activated sludge have been tabulated in Table VII. A glucose dose of 935 p.p.m. was given to 3150 p.p.m. of sludge in this test and Column 1 in the table shows that the glucose was removed steadily, the removals obtained ranging from 144 p.p.m. in 1½ hours to 885 p.p.m. in 24 hours. The quantities of oxygen utilized by the sludge-glucose mixture and the control mixture are given in Columns 2 and 3. The quantity of sludge found in the sludge-glucose mixture increased regularly during the first 10 hours and decreased somewhat thereafter as shown in Column 4. The rate at which the sludge solids increased and decreased again varies in different experiments

and depends upon the rate of glucose metabolism. The quantity of sludge remaining in the control was calculated from the oxygen used in the control as previously described. The quantities of glucose that may be accounted for by an increase in sludge solids as a result of the glucose metabolism increased from 116 p.p.m. after 1½ hours to 561 p.p.m. after 24 hours. The percentages of glucose removed that can be accounted for by the increase in sludge solids and by oxidation are given in Columns 7 and 8 respectively. It will be noted that 80.6 per cent of the glucose removed is accounted for as an increase in sludge solids after 1½ hours of aeration and that this percentage falls to 63.4 per cent after 24 hours. When the percentage glucose removal accounted for as an increase in sludge solids is added to the percentage

TABLE VII.—*Sludge Production During Glucose Metabolism by Activated Sludge*

Experiment G-79. Initial Suspended Solids, 3150 p.p.m. Glucose Dose 935 p.p.m.

Aeration Time, Hours	Glucose Removed from Solution, P.p.m.	Oxygen Utilized by P.p.m.		Sludge Found in Sludge-Glucose Mixture, P.p.m.	Sludge Remaining in Control Mixture, P.p.m.	Glucose Accounted for by Increase in Sludge Solids, P.p.m.	Percentage of Glucose Removed that is Accounted for by		
		Sludge-Glucose Mixture	Sludge Control Mixture				Increase in Sludge Solids	Oxidation	Increase in Solids and Oxidation
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1½	144	61.9	22.3	3241	3125	116	80.6	25.7	106.3
3	280	107.4	33.9	3320	3112	208	74.3	24.6	98.9
4½	395	166.8	57.5	3384	3086	298	75.4	25.9	101.3
6	508	213.9	67.0	3446	3075	371	73.0	27.1	100.1
10	756	325.3	115.4	3569	3021	548	72.5	26.0	98.5
24	885	525.2	230.8	3452	2891	561	63.4	31.2	94.6

(5) These values are obtained by subtracting the products of the factor 1.12 and column 3 from the initial suspended solids.

(6) = (4) − (5).

(7) = (6) × 100 ÷ (1).

(8) Calculated as shown in column 6 in Table I.

accounted for by oxidation, it will be noted (Column 9) that practically all of the glucose removed has been accounted for at each observation interval. In fact, the values obtained in this experiment all seem to be within the experimental limits of error. This is not always the case, for in some experiments only 70 to 90 per cent of the glucose removed has been accounted for by the data obtained and treated in this manner. However, the percentages of glucose removed that are accounted for by an increase in solids, remained very similar to the values given in Table VII. The percentages accounted for by oxidation vary considerably as already shown in Table III.

Similar experiments upon the production of sludge during glucose feeding were performed with pure culture sludges formed by single

strains of zoogleal bacteria, developed upon synthetic sewage [4] which contained no glucose. The data for a typical experiment with such sludge are given in Table VIII. These data were obtained and treated in the same manner as the data for normal sludge as given in Table VII. It will be noted that the percentages of glucose removed, that may be accounted for by solids formation by pure zoogleal cultures, are decidedly lower than for normal activated sludge. On the other hand, the percentage of the glucose removed that is completely oxidized, is higher for the pure zoogleal culture than for normal activated sludge. These results warrant concluding that there is a definite difference be-

TABLE VIII.—*Sludge Production During Glucose Metabolism by Pure Culture Zoogleal Sludge*

Strain No. 86.

Initial Culture Solids 686 p.p.m. Glucose Dose 505 p.p.m.

Aeration Time, Hours	Glucose Removed from Solution, P.p.m.	Oxygen Utilized by P.p.m.		Sludge Found in Sludge-Glucose Mixture, P.p.m.	Sludge Remaining in Control Mixture, P.p.m.	Glucose Accounted for by Increase in Sludge Solids, P.p.m.	Percentage of Glucose Removed that is Accounted for by		
		Sludge-Glucose Mixture	Sludge Control Mixture				Increase in Sludge Solids	Oxidation	Increase in Solids and Oxidation
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1½	71.2	35.6	6.8	702	678	24	33.9	37.9	71.8
3	153.0	63.9	15.4	734	669	65	42.5	29.7	72.2
4½	217.0	89.5	27.0	752	656	96	44.2	27.0	71.2
6	293.0	113.9	27.8	772	655	117	39.9	27.4	67.3
24	438.0	259.6	76.6	800	600	200	45.7	39.0	84.7

(5) These values are obtained by subtracting the product of the factor 1.12 and column 3 from the initial suspended solids.

(6) = (4) − (5).

(7) = (6) × 100 ÷ (1).

(8) Calculated as shown in Column 6 in Table I.

tween the aerobic metabolism of glucose by pure zoogleal cultures and that by normal activated sludge. The normal sludge in every case seems to assimilate and synthesize a greater portion of the glucose removed from solution. The quantity of dissimilation products other than CO_2 obtained with both normal activated and pure culture sludge seems to be but a small fraction of the glucose removed.

METABOLISM OF GLUCOSE IN GLUCOSE ACCLIMATED SLUDGE

The acceleration of the glucose removal rate by activated sludge with repeated glucose feeding was first noted by Smit [11] and was clearly demonstrated in the previous paper.[1] It has been suggested [1] that one of the reasons for this acclimatization phenomenon was the development of adaptive glucose enzymes by the predominant bacteria of the

sludge. To determine if this might be the case, and whether the glucose metabolism was influenced by such possible acclimatizations, a number of experiments were carried out with pure culture zoogleal sludges. These sludges were developed on synthetic sewage in the bacteriological laboratory. When the cultures contained about 800 p.p.m. of bacterial suspension they were divided into two portions. The feeding of synthetic sewage (containing no glucose) was continued on one portion while the second portion was fed with synthetic sewage fortified with 500 p.p.m. of glucose for four or five days. The glucose metab-

TABLE IX.—*The Influence of Previous Glucose Feeding upon the Removal of Glucose from Solution by Pure Culture Zoogleal Sludge*

(Mean for 3 Pairs of Experiments)
Mean Glucose Dose, Non-acclimated Cultures 493 mgm. per liter
Mean Glucose Dose, Acclimated Cultures 485 mgm. per liter

Aeration Time, Hours	Mgm. of Glucose Removed from Substrate per Gram of Sludge per Liter in Indicated Time		Percentage of the Glucose Removed from Substrate by One Gram of Sludge per Liter in Indicated Time	
	Non-Acclimated	Acclimated	Non-Acclimated	Acclimated
1½	158	252	32.0	52.0
3	228	328	46.2	67.6
4½	277	357	56.2	73.6
24	483	439	98.0	90.5

TABLE X.—*Mean Percentage Metabolism of Glucose Removed from Solution by Normal Activated Sludge and Pure Culture Zoogleal Sludge*

Aeration Time, Hours	Normal Activated Sludge			Pure Culture Zoogleal Sludge		
	Synthesized to Sludge	Oxidized to CO_2	Total Accounted for	Synthesized to Sludge	Oxidized to CO_2	Total Accounted for
1½	77.3	13.6	90.9	39.0	31.0	70.0
3	70.5	14.6	85.1	49.4	33.1	82.5
4½	71.2	15.0	86.2	58.1	33.5	91.6
6	71.2	16.7	87.9	50.7	32.0	82.7
24	73.3	17.8	91.1	48.4	45.1	93.5

olism tests were then made upon these two portions. The glucose removal results obtained in these experiments have been summarized in Table IX. These data show that treatment of these cultures for a few days with glucose accelerated very decidedly the rate of glucose removal. These experiments indicate that the mechanism of glucose removal is adaptive for these strains of bacteria and can be accelerated by proper feeding procedures.

Careful study of data obtained in all glucose metabolism experiments failed to show any difference in this metabolism before and after

glucose acclimatization with either normal activated sludge or pure culture zoogleal sludge. The results of all experiments on metabolism with pure culture and normal activated sludge have, therefore, been summarized in Table X. This table indicates the difference in the mean metabolism of glucose by the two kinds of sludges. It shows that the percentage of oxidation is higher and that the percentage of glucose synthesized is considerably lower for these zoogleal cultures than for normal activated sludge.

Possible Assimilation Products of Glucose Metabolism

An attempt was made to determine whether the fat, fatty acids and hydrogel content of activated sludge were changed by the prolonged assimilation of glucose. An analysis of activated sludge before and after 60 doses of sewage containing 500 p.p.m. of glucose over a 30-day period was made. All of the glucose fed in this period was metabolized by the sludge. The methods of analysis used by Knechtges, Peterson and Strong [12] for fats and free fatty acids in sludge were employed. The results indicated no appreciable change in either of the above constituents. However, the question of variation or change in the hydrogel content of the sludge has not yet been definitely answered.

Discussion

All of these data indicate that glucose was removed biologically from solution at a much higher rate than oxidation of glucose occurred. With normal activated sludge the glucose was removed from 5 to 7 times as fast as the rate of its decomposition as measured by oxygen consumption and CO_2 production. Zoogleal sludge removed glucose at about three times the rate at which it was oxidized to CO_2. This fact has not been pointed out for activated sludge or zoogleal sludges before. Hawkins and Van Slyke,[13] however, found that the rate of glucose removal took place more than twice as fast as the rate of decomposition measured by CO_2 production during the initial stages of fermentation by yeasts. Wilson and McLachlan,[14] in studying the carbon dioxide production in the activated sludge process express the view that carbon dioxide is not the only product of aerobic oxidation. Following a study of the carbon balance in the process upon a laboratory scale they conclude that only about 10 per cent of the transformation products of carbon appear as CO_2. They suggested the possibility of dehydrogenation in the process but did not demonstrate any dissimilation product other than CO_2. Our data on CO_2 production, while somewhat higher, roughly confirm their findings. Dehydrogenation products of dissimilation, however, could not be found and in this respect our findings confirm those of Smit.[11] Watkins [15] isolated a number of strains of bacteria from activated sludge and sprinkling filter slime which attacked glucose without acid formation as a dissimilation product and it seems probable that these organisms metabolized glucose in a way similar to activated sludge and the pure culture zoogleal sludge.

In a study of the synthesis of cell substance by yeast under vigorous aerobic conditions, Fink and Krebs [16] reported a yield of 52 per cent of dry substance from one per cent sugar solutions. Their results indicated that an increase in the percentage of cell substance was obtained as the percentage of sugar was decreased. Winzler and Baumberger [17] reached the conclusion that, in the presence of oxygen, yeasts burned 26.5 per cent of the glucose which disappeared from the medium and stored 73.5 per cent of it as intracellular carbohydrate. This synthesis was demonstrated by the results obtained from the heats of formation and the heat production measured during exogenous respiration. The results of the above investigators upon yeasts with entirely different methods are remarkably similar to the percentages of oxidation and synthesis of glucose obtained on these studies with activated sludge. It is not intended to imply that yeasts are involved in the activated sludge process. While yeasts may be present in the sludge, they are certainly not the predominant organisms. Our data support the work of Winzler and Baumberger in regard to the percentage of glucose that may be assimilated as intracellular carbohydrate in respiring bacterial processes. Werkman [18] defines bacterial respiration (aerobic dissimilation) as a process utilizing molecular oxygen as a hydrogen acceptor. The activated sludge metabolism of glucose conforms to this definition. However, in the metabolism of glucose by activated sludge only a small portion of the glucose that disappears is consumed in the respiratory process and a large portion of the glucose is stored. Consequently aerobic dissimilation is descriptive of only the minor portion of this process. As most of the glucose is stored in the process, assimilation and not dissimilation should be emphasized. It would seem therefore that this metabolism can best be described in the terminology of Clifton and Logan [19] as an oxidative assimilation. In the words of these authors the results "suggest that respiration and assimilation are closely connected processes and the respiration of heterotropic bacteria may well be expressed by the general equation:

$$\text{Foodstuff} + O_2 \xrightarrow{\text{oxidative assimilation}} \text{Assimilated material} + CO_2 + H_2O;$$

much as $CO_2 + H_2O + \text{light} \longrightarrow (CH_2O) + O_2$ represents the assimilatory process in the green plant." With glucose the activated sludge process by this oxidative assimilation mechanism transforms over 60 per cent of the foodstuff to assimilated material.

It has been shown that glucose was metabolized in a different way than peptone or sewage by activated sludge and that a much greater assimilation and synthesis occurred with glucose than with peptone or sewage. When glucose alone in doses up to 1000 p.p.m. is fed to normal activated sludge, rapid assimilation occurs and it is inferred that the sludge already contains sufficient nitrogen and mineral constituents to metabolize the glucose. When domestic sewage containing large quantities of glucose (500 to 1000 p.p.m.) is fed repeatedly to activated sludge, the sewage apparently furnished sufficient nitrogen and

mineral constituents for metabolic purposes for the glucose is rapidly assimilated as shown. It is this fundamental difference that explains the much greater production of solids obtained by feeding glucose to activated sludge or pure cultures of zoogleal bacteria. Glucose is not only removed from solution at a somewhat higher rate than peptone but a considerably greater proportion of it is assimilated to appear as protoplasm in either of these biological systems.

Applying the above facts to practical plant operation, the production of larger volumes of sludge would be expected with sewage containing glucose wastes, even in the absence of sludge bulking. The larger the glucose content of the sewage the greater the volume of sludge that is to be expected at the plant for any practical period of aeration. For this reason it is apparent that a ratio of capacities of plant aeration to settling that is satisfactory for domestic sewage might be unsatisfactory for sewage containing carbohydrate wastes. As more sludge would be synthesized from such sewage, greater settling tank capacity would have to be provided, a smaller portion of the sludge produced would be needed for sludge return and a larger portion would have to be disposed of.

Summary and Conclusions

The oxygen relationships of the glucose removal reaction by activated sludge and pure culture zoogleal sludge were studied. It was shown that the percentages of glucose removed that were oxidized varied from 4.0 to 24.0 per cent after 1½ hours and from 11.3 to 31.8 per cent after 24 hours of aeration with activated sludge. Pure culture zoogleal sludges oxidized on the average 31.0 per cent in 1½ hours and 45.1 per cent in 24 hours of the glucose that they removed. It was shown that 1000 p.p.m. of glucose with an L value (total carbonaceous biochemical oxygen demand) of 1067 p.p.m. when added to a normal activated sludge, did not increase the short time oxygen requirement of the sludge-feed mixture to as great an extent as 500 p.p.m. of peptone with a much lower L value. This is true even when ammonia nitrogen is not being oxidized. This may be explained by differences in the metabolism of these two materials by activated sludge. Repeated feeding of sewage containing 500 p.p.m. of glucose did not increase the short time oxygen demand per gram of sludge sufficiently to be detrimental to the substrate oxidation ability of the sludge.

A search for dissimilation products of glucose metabolism was made. It was found that once the glucose was removed from solution, it could not be recovered by simple extraction processes. The glucose removal reaction was, therefore, considered to be the result of biological metabolism following adsorption and not simple adsorption upon the surfaces of the floc. The respiratory quotient of glucose metabolism by activated sludge was 1.0. Other dissimilation products besides CO_2 could not be demonstrated by drops in pH during the reaction nor could such products be recovered by steam distillation of the sludge. It was

observed that glucose removal and total carbonaceous biochemical oxygen demand removal of glucose were practically equivalent. From this it was concluded that other soluble dissimilation products were either not formed at all or not formed to a sufficient extent to be discharged into the substrate liquor.

The increase in sludge solids was studied as a measure of glucose metabolism and assimilation. Because of the biological character of the reaction, suspended solids were followed in both an activated sludge-glucose mixture and in an unfed sludge mixture as a control. The differences in solids following short periods of aeration represent the glucose assimilation. Such observations indicated that almost 80 per cent of the glucose removed is assimilated and appears as protoplasm within 1½ hours of aeration. This percentage of assimilation slowly falls as the aeration is continued, but even after 24 hours over 70 per cent of the glucose removed can still be accounted for by the increase in sludge solids. A similar but somewhat lower assimilation and synthesis was demonstrated for pure culture zoogleal bacteria. It was shown that the mechanism of glucose removal by pure zoogleal cultures was adaptive and could be accelerated by repeated doses of a balanced feed containing glucose. An increase in fats or fatty acids could not be demonstrated in sludge which had assimilated glucose for a 30-day period. From 80 to 100 per cent of the glucose removed can be accounted for as the sum of the glucose oxidized and that assimilated to protoplasm. On the basis of these experiments, it must be concluded that the removal of glucose from solution by normal activated sludge and pure cultures of zoogleal bacteria is largely an oxidative assimilation reaction. In this reaction the greater part of the glucose is assimilated and appears as protoplasm within the sludge in a few hours after the glucose is fed. Dissimilation products other than carbon dioxide cannot be demonstrated during this metabolism and, upon the basis of these data, can in any case represent only a relatively small fraction of the glucose metabolized.

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ANALYSIS OF THE BIOCHEMICAL OXYGEN DEMAND CURVE

By Harold A. Thomas, Jr.

Instructor in Sanitary Engineering, Harvard Graduate School of Engineering, Cambridge, Mass.

In a previous publication,[1] a simplified method of evaluating the constants of the equation of the first stage of the biochemical oxygen demand curve was described. This procedure, called the "slope" method, has subsequently been adapted to the formulation of a variety of reactions of importance in sewage research. Reactions such as the aerobic and anaerobic decomposition of sewage, the growth and death of organisms, the interchange of gases at a liquid interface, and the disinfection of sewage may all be expressed by the unimolecular reaction type equation, and hence may be analyzed by the "slope" method. Moreover, with the growing interest in such problems as the oxygen balance in polluted waters, it is certain that the sanitary engineer will be concerned more than ever with the magnitude and reliability of the constants involved in the formulated behavior of sewage. There is submitted, therefore, an extension of the "slope" method that is believed to provide a new and rapid procedure for formulating experimental studies, particularly those dealing with oxygen demand, so as to disclose all of the information of particular value to both the designing engineer and the experimenter.

The original analysis is extended in this paper to include the important case of data exhibiting a time lag. Theoretically, no reaction in biochemistry can occur in exact accordance with the unimolecular reaction; at the start the process must always be subject to an acceleration phase, of which account is taken in the autocatalytic formulation but which must be called a "lag" period when the simple unimolecular reaction is to be retained. Previously, in treating data possessing a lag, it has been customary to assume a value for the length of the lag period, or to shift the origin of the system to a point presumably lying on the unimolecular portion of the curve. These are arbitrary procedures, likely to introduce a serious error in the subsequent evaluation of the constants in the final equation. In the method to be described the assumption of a value for the lag period with its concomitant error is obviated.

In general the duration of the lag period depends upon the nature of the experiment; it frequently constitutes a large portion of the total time of the reaction. Consequently it is often desirable to obtain an accurate measure of the lag period itself, aside from the necessity of its determination in precisely fitting the equation to the rest of the curve.

Determination of the Lag Period.—The equation expressing the unimolecular reaction may be written so as to include the time lag, t_0, in the following form:

$$y = L(1 - 10^{-k(t-t_0)}) = L(1 - C10^{-kt}) \qquad (1)$$

where in the case of B.O.D. measurements,

y = the B.O.D. exerted in time t;
L = the ultimate B.O.D. at the end of the stage;
k = the reaction velocity constant;
t_0 = the value of t at the end of the lag period, that is the value of t when $y = 0$; and
C = a constant = 10^{kt_0}.

If t_0 becomes zero, equation (1) reverts to the usual form with no lag period. If a lag period does exist, equation (1) is valid only for positive values of $(t - t_0)$.

As mentioned, previous methods of fitting equation (1) have involved an initial assumption in order to establish the origin of coordinates. This arbitrary step is eliminated in the slope method since the latter is based on the equation

$$\frac{dy}{dt} = y' = 2.303k(L - y) \tag{2}$$

obtained by differentiation from equation (1). Equation (2) is independent of recorded values of time; therefore it provides a method of computing the constants k and L without a foreknowledge of the lag period t_0. With the evaluation of k and L, the proper value of t_0 may be determined by a simple least squares treatment of equation (1). This treatment involves the usual condition that the sum of the squares of the residuals, $r = L - LC10^{-kt} - y$, be a minimum. That is,

$$\Sigma r^2 = \Sigma(L - LC10^{-kt} - y)^2 = \text{a minimum.}$$

Therefore

$$\frac{\partial \Sigma r^2}{\partial C} = 2\Sigma r \frac{\partial r}{\partial C} = 0.$$

Since

$$\frac{\partial r}{\partial C} = -L10^{-kt}$$

$$\Sigma(L - LC10^{-kt} - y)(-L10^{-kt}) = 0$$

or

$$L\Sigma 10^{-kt} - LC\Sigma 10^{-2kt} - \Sigma y 10^{-kt} = 0$$

and

$$C = \frac{L\Sigma 10^{-kt} - \Sigma y 10^{-kt}}{L\Sigma 10^{-2kt}}. \tag{3}$$

Finally, the lag period may be calculated from the relation

$$t_0 = 1/k \log C. \tag{4}$$

A summary of the equations of the slope method, including equations (3) and (4), is presented in Table I. Before introducing an example illustrating the use of the equations, it will be of interest to consider another way in which the original method may be extended to yield additional information.

Reliability of k and L.—Having determined the values of k and L from a given experiment, the following questions may arise;

(a) How closely do the data follow an equation of the unimolecular type?
(b) If the experiment could be duplicated independently, how precisely might the new values of k and L be expected to check with those already determined?

These questions are closely related. They introduce the problem of determining the reliability of the constants k and L. Theriault and Reed [2] have used a method of comparing the precision attained in their oxygen depletion studies that is based on summing the squares of the deviations of experimental from computed points in each series. While this method is quite adequate for the purpose intended, it is not adapted to the determination of the probable error in the constants k and L.

The procedure for estimating the reliability of constants of a linear equation determined by a least squares fit from experimental data may be found in nearly any standard text on the theory of least squares.[3] In carrying out the procedure it is first necessary to determine the probable errors in the quantities a and b, where, as in the original method, $a = 2.303kL$, and $b = -2.303k$. These probable errors are

$$E_a = 0.674\sqrt{\frac{\Sigma y^2}{n\Sigma y^2 - [\Sigma y]^2} \times \frac{\Sigma R^2}{n-2}} \tag{5}$$

and

$$E_b = 0.674\sqrt{\frac{n}{n\Sigma y^2 - [\Sigma y]^2} \times \frac{\Sigma R^2}{n-2}}. \tag{6}$$

Here

E_a and E_b = the probable errors in a and b respectively;
ΣR^2 = the sum of the squares of the residuals, where
$R = y'_{\text{calculated}} - y'_{\text{measured}}$;
n = the number of pairs of values y and y'.

The probable errors in k and L (E_k and E_L) may be determined from equations (5) and (6) and the equations relating a and b with k and L, as follows:

$$E_k = 0.4343E_b \tag{7}$$

and

$$E_L = \sqrt{\left(\frac{E_a}{b}\right)^2 + \left(\frac{aE_b}{b^2}\right)^2}. \tag{8}$$

Equations (5), (6), (7) and (8) are included in Table I in a form to facilitate computation.

TABLE I.—*Summary of Slope Method*

Part 1. Given $(n+2)$ sets of experimental points y vs t, compute the n corresponding values of y', where

$$y_i' = \frac{(y_i - y_{i-1})\left(\frac{t_{i+1} - t_i}{t_i - t_{i-1}}\right) + (y_{i+1} - y_i)\left(\frac{t_i - t_{i-1}}{t_{i+1} - t_i}\right)}{(t_{i+1} - t_{i-1})}$$

and evaluate the quantities Σy, $\Sigma y'$, $\Sigma yy'$ and Σy^2. Calculate k and L [Steps (1) and (2); Part 2]. With relation

$$R = |y'_{\text{calc.}} - y'| = |2.303k(L - y) - y'|$$

evaluate ΣR^2. Finally calculate $\Sigma 10^{-kt}$, $\Sigma 10^{-2kt}$ and $\Sigma y 10^{-kt}$. Then obtain remaining constants in Steps (3), (4) and (5) in the following:

Part 2

Step	Compute First	Obtain
(1)	$-b = -\dfrac{n\Sigma yy' - \Sigma y\Sigma y'}{n\Sigma y^2 - (\Sigma y)^2}$	$k = 0.4343(-b)$
(2)	$a = \dfrac{\Sigma y^2\Sigma y' - \Sigma yy'\Sigma y}{n\Sigma y^2 - (\Sigma y)^2}$	$L = -\dfrac{a}{b}$
(3)	$E_b = 0.674\sqrt{\dfrac{n}{n\Sigma y^2 - (\Sigma y^2)}} \times \dfrac{\Sigma R^2}{(n-2)}$	$E_k = 0.4343E_b$
(4)	$E_a = 0.674\sqrt{\dfrac{\Sigma y^2}{n\Sigma y^2 - (\Sigma y^2)}} \times \dfrac{\Sigma R^2}{(n-2)}$	$E_L = \sqrt{\left(\dfrac{E_a}{b}\right)^2 + \left(\dfrac{aE_b}{b^2}\right)^2}$
(5)	$C = \dfrac{L\Sigma 10^{-kt} - \Sigma y 10^{-kt}}{L\Sigma 10^{-2kt}}$	$t_0 = \dfrac{\log C}{k}$

E_k and E_L may be interpreted according to the usual definition of the probable error. For example, suppose that in a B.O.D. test conducted on domestic sewage at 23°C., the computed value of k for the first stage was 0.140 and the corresponding value of E_k was found to be 0.006. Then, according to the definition of the probable error, there exists a "fifty-fifty" chance that the true value of k will fall somewhere within the range 0.140 ± 0.006 or $0.134 < k < 0.146$.* Evidently the smaller the probable error, the greater the reliability of the constant. From equations (5), (6), (7) and (8), it may be seen that the probable errors decrease as the number of experimental points, n, increase. It should be noted that for the definition to apply rigorously, n should be fairly large and the values of the probable errors, E_k and E_L, should be small in comparison with the values of k and L. However the general aid provided by E_k and E_L in determining the adequacy of the experimental data and the adaptability of the analysis to the purposes desired is more important to the analyst than their literal interpretation of probable errors.

Example.—To illustrate the application of the foregoing principles, the author has selected a set of B.O.D. experiments made on samples collected simultaneously from the influent and effluent of a New England activated-sludge plant. The object of the research was to ascertain the effect of seeding upon the oxygen demand. To those engaged in the solution of problems connected with the disposal of municipal wastes in receiving waters, this type of experiment is of particular interest, since the important factor of seeding has received comparatively little attention in comparison

* The true value of k, presumably, could be determined by averaging the values of k obtained from a large number of B.O.D. tests on the same sample conducted under the same conditions.

with other well investigated factors in the B.O.D. test, such as temperature and dilution water.

The test was performed in four groups of bottles as follows: Group A—influent, unseeded; Group B—influent, seeded; Group C—effluent, unseeded; and Group D—effluent, seeded. The standard technique was observed; the dilution water was buffered with sodium bicarbonate; and the temperature of incubation was 23°C. The azide modification was used in all dissolved oxygen determinations. The seeding liquor consisted of a well nitrified sewage, rich in protozoa, particularly the ciliates. This sewage had been maintained at the incubation temperature in an aerobic condition for a period of three weeks previous to the B.O.D. tests. In order to approximate actual river conditions, a relatively large amount of seeding liquor (15 per cent on basis of volatile solids) was added to the sewage. The results, corrected for the demand of the seeding liquor, are presented in Table II and are plotted in Fig. 1.

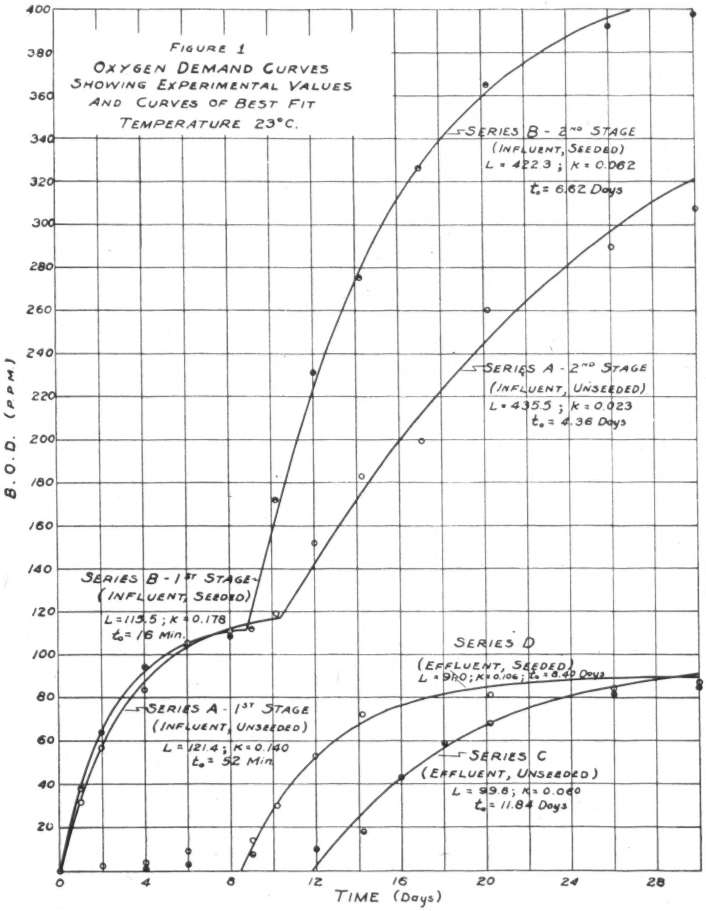
TABLE II.—*Results of B.O.D. Determinations. Temperature 23°C.*

Time (days)	Group A Influent Unseeded (p.p.m.)	Group B Influent Seeded (p.p.m.)	Group C Effluent Unseeded (p.p.m.)	Group D Effluent Seeded (p.p.m.)
0	0	0	0	0
1	32	38	—	—
2	57	64	—	2.3
4	84	94	0.8	4.0
6	106	104	3.0	9.2
8	111	109	—	—
9	112	112	7.6	14
10.2	119	172	—	30
12	152	231	10	54
14.2	183	275	18	72
16	—	—	43	—
17	199	326	—	—
18	—	—	59	—
20.2	260	364	68	81
26	290	392	82	85
30	307	398	85	86

Each point on the curve represents the average demand from four bottles titrated simultaneously. It is believed that the final values represent an unusually complete and precise B.O.D. study. Since the data exhibit a variety of lag periods as well as a variety of magnitudes of the other constants, they are well suited to the exposition of the formulas in Table I.

It may be seen from Fig. 1 that the curves for the influent (A and B) show both the carbon-oxidizing and the nitrification stages. In accordance with a formulation used by Streeter,[4] each of the two stages of the influent curves was expressed by a unimolecular reaction type equation with a properly determined lag period. The two effluent curves were expressed each by a single stage unimolecular reaction equation. The com-

putations resulted in the values of t_0, k, L, E_k, and E_L listed in Table III for the six equations occurring in the four series. For aid in generalization, the values of the relative probable errors of k and L are included in Table III.



Sample Calculation.—An example of the calculations involved in evaluating the constants in Table III is presented in Table IV for the second stage of Group B. The computations for this curve begin with the value of B.O.D., $y = 172$, when $t = 10.2$ days, since this is the first point definitely on the second stage of the curve.

TABLE III.—*Values of Parameters for Groups A, B, C, and D Obtained by the "Slope" Method. Temperature 23°C.*

Group	Description	Stage to		$k \pm E_k$ (per day)	$L \pm E_L$ (p.p.m.)	Per Cent Rel. Error $k=(E_k \div k) \times 100$	Per Cent Rel. Error $L=(E_k \div L) \times 100$
			(days)				
A	Influent unseeded	1	0.036	0.140 ±0.006	121.4± 6.6	4.3	5.4
A	Influent unseeded	2	4.36	0.0228±0.0098	435.5±211.0	43.0	48.5
B	Influent seeded	1	0.011	0.178 ±0.005	115.5±4.0	2.8	3.5
B	Influent seeded	2	6.62	0.062 ±0.003	422.3±25.6	4.8	6.1
C	Effluent unseeded	–	11.84	0.060 ±0.014	99.8±27.3	23.4	27.4
D	Effluent seeded	–	8.40	0.106 ±0.013	91.0±14.0	12.2	15.4

TABLE IV.—*Calculations of the Constants of the Second Stage of B.O.D. for Group B*

Part 1

t	y	y'	$y'y$	y^2	$y'_{calc.}$	R	R^2	10^{-kt}	10^{-2kt}	$y10^{-kt}$
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
10.2	172*	—	—	—	—	—	—	0.230	0.0529	39.560
12	231	27.02†	6,237.0	53,361	27.62	0.60	0.360	.178	.03168	41.118
14.2	275	21.15	5,816.2	75,625	21.27	0.12	0.014	.1292	.01669	35.530
17	326	15.25	4,971.5	106,276	13.91	1.34	1.796	.0862	.00743	28.101
20.2	364	9.35	3,403.4	132,496	8.42	0.93	.865	.0546	.00298	19.874
26	392	2.85	1,117.2	153,664	4.38	1.53	2.341	.0238	.00057	9.330
30	398*	—	—	—	—	—	—	.0133	.00017	5.293
Sum	1,588	75.6	21,545.3	521,422			5.376	0.7151	0.11242	178.806

* Not included in sum.

(1) Time in days (Table II).

(2) B.O.D. measured in stated time (Table II).

(3) $$y_n' = \frac{(y_n - y_{n-1})\left(\frac{t_{n+1} - t_n}{t_n - t_{n-1}}\right) + (y_{n+1} - y_n)\left(\frac{t_n - t_{n-1}}{t_{n+1} - t_n}\right)}{(t_{n+1} - t_{n-1})}$$

$$27.02\dagger = \frac{(231 - 172)\left(\frac{14.2 - 12}{12 - 10.2}\right) + (275 - 231)\left(\frac{12 - 10.2}{14.2 - 12}\right)}{(14.2 - 10.2)}.$$

(4) Column (3) × Column (2).

(5) Column (2) squared.

(6) $y'_{calc.} = 2.30k(L - y) = 0.1444(422.3 - y)$; k and L obtained from Steps 1, 2, Part 2.

(7) $R = |y'_{calc.} - y'| = |$Column (6) − Column (3)$|$.

(8) Column (7) squared.

(9) $10^{-0.0623t}$; values of t from Column (1).

(10) Column (9) squared.

(11) Column (9) × Column (2).

Part 2 (Arranged to correspond to Table I, Part 2)

Step	Compute First	Obtain
(1)	$-b = -\frac{5(21{,}545.3) - (1588)(75.6)}{5(521{,}422) - (1{,}588)^2} = 0.1444$	$k = 0.4343(0.144) = 0.0625$
(2)	$a = \frac{(521{,}422)(75.6) - (21{,}545.3)(1{,}588)}{5(521{,}422) - (1{,}588)^2} = 60.978$	$L = \frac{60.978}{0.1444} = 422.3$
(3)	$E_b = 0.674\sqrt{\frac{5}{5(521{,}422) - (1{,}588)^2} \times \frac{5.376}{(5-2)}} = 0.0069$	$E_k = 0.4343(0.0069) = 0.003$
(4)	$E_a = 0.674\sqrt{\frac{521{,}422}{5(521{,}422) - (1{,}588)^2} \times \frac{5.376}{3}} = 2.24$	$E_L = \sqrt{\left(\frac{2.24}{0.144}\right)^2 + \left(\frac{60.98 \times 0.0069}{0.144^2}\right)^2} = 25.6$
(5)	$C = \frac{422.3(0.7151) - 178.806}{422.3(0.1124)} = 2.595$	$t_0 = \frac{\log 2.595}{0.0625} = 6.62$ (days)

Conclusions.—The following information may be deduced from the experiment and its mathematical analysis:

1. The nitrification stage of biochemical oxidation may be adequately represented by an equation of the unimolecular type with a properly fitted lag period. In the sewage tested the reaction velocity constant k for the nitrification stage was about 20 to 30 per cent of the corresponding value of k for the first stage of biochemical oxygen demand. The ratio of the B.O.D. at the end of the nitrification stage to that at the end of the first stage was about 4 : 1. Other studies, including investigations by Theriault [2] and Mohlman [5] indicate that this ratio may have a value any where in the range 2 : 1 to 5 : 1 depending upon the chemical composition of the sewage.

2. The B.O.D. of the effluent may be represented by a single stage unimolecular curve. These curves possess lag periods similar to those obtained for the nitrification stage of the influent. Moreover the values of k for the effluent are intermediate between those of the first and second stages of the influent curves. These facts together with the observation that the ultimate B.O.D., L, of the effluent curves is about one-fourth that of the influent curves would indicate that the demand of the effluent is essentially due to nitrification. Since some nitrification does inevitably occur in normal operation of an activated sludge plant, it is reasonable to believe that the effluent was well supplied with nitrifying bacteria, and should be regarded as already seeded. This is borne out by the nearly identical values of k for Group C and the second stage of Group B. It should be noted that the formulation of the data is in accord with the fact, pointed out by Molhman,[5] that the percentage of B.O.D. removed tends to decrease progressively with time.

3. Seeding increases the rate of demand, as may be seen in Fig. 1, or by comparison of the values of k in Table III of Groups A and C with those of B and D. The increase in k with seeding is most marked in the nitrification stage and in the effluent tests. Another important effect of seeding is the reduction of the lag period in the B.O.D. of the effluent, and a decrease in the time of the beginning of the second stage in the B.O.D. of the

influent.* It is notable that in all groups the seeding produced no significant change in the value of the ultimate demand L.

4. In each group the relative error in k tends to be about the same as the relative error in L. An erratic series of experimental points, such as that in Group C, produces about the same large relative error in the value of the constants k and L. Larger errors are noted in the second stages of the influent curves than in the corresponding first stages. The reduction in precision during the second stage is a characteristic of the dilution method and perhaps accounts for the fact that the second stage has seldom been formulated. It is interesting to note that the errors in the seeded groups are much smaller than in the unseeded groups. This would indicate that the discrepancy in the demand commonly observed among different bottles of the same test when titrated simultaneously might be partly eliminated by a larger initial seeding.

A number of B.O.D. tests have been analyzed by the extended slope method. In general it may be said that the value of k and L for the first stage calculated from B.O.D. tests that have been conducted carefully are subject to probable errors ranging from 5 to 25 per cent. In the second stage or in effluent demands these constants usually possess higher relative errors in the range 15 to 65 per cent.

Summary.—A method of computing the lag period and probable errors of the constants in the equation of the unimolecular reaction has been described. In applying this method to a B.O.D. test it is demonstrated that initial seeding may change the shape of the oxygen demand curve considerably. This change is characterized by an increase in the reaction velocity constant, k, a decrease in the relative probable errors in k and L (the ultimate demand), and a decrease in the time of occurrence of the nitrification stage.

References

1. Harold A. Thomas, Jr., "'Slope' Method of Evaluating the Constants of the First-Stage B.O.D. Curve." THIS JOURNAL, **9**, 425–430 (1937).
2. E. J. Theriault, "The Oxygen Demand of Polluted Waters." U. S. Pub. Health *Bulletin*, **173** (1927).
3. A. F. Palmer, "Theory of Measurements." McGraw-Hill Book Co.
4. H. W. Streeter, "Measures of Natural Oxidation in Polluted Streams." THIS JOURNAL, **7**, 273 (1935).
5. F. W. Mohlman, G. P. Edwards, and Gladys Swope, "Technic and Significance of the B.O.D. Determination." *Ind. and Eng. Chem.*, **20**, 242–246 (1928).

* The time of the beginning of the nitrification stage may be expressed with sufficient accuracy as

$$t' = t_0 + \frac{1}{k} \log \frac{L_T}{L_T - L_c}$$

where t' = time of beginning of nitrification; t_0 = the lag period of the second stage; k = the reaction velocity constant of second stage; and L_T and L_C = the respective values of the ultimate B.O.D. at the end of the second and first stages.

Plant Operation

SOME OBSERVATIONS ON SEWAGE SEDIMENTATION

By Norman C. Wittwer

Supervising Sanitary Engineer, Sewage Treatment Works, Rahway Valley (New Jersey)
Joint Meeting

The subject of sewage sedimentation is one which has been extensively explored in the past by many workers in the field of sanitary engineering, among them being Allen Hazen, Emil Kuichling, Professor Camp, George Schroepfer, and others. It is therefore with due humility that the writer offers the observations contained herein in the hope that they may add in some measure to our store of knowledge on this subject, and help to crystallize some of the factors in sewage sedimentation at present not too well understood.

Modern sewage settling tanks are used for a variety of purposes such as, for example, the removal of grit, the removal of raw suspended solids, the settling of activated sludge, and the settling of sprinkling filter effluent. Since the material to be handled in each of these cases differs widely, the design and physical characteristics of settling tanks must vary accordingly.

This article will deal principally with the requirements for the primary sedimentation of raw sewage, and the correlation of the strength of raw sewage with settling tank performance. All data used in this study were obtained from the records of the Rahway Sewage Treatment Plant, located in Rahway, New Jersey. This plant has been previously described in detail by the author in the January, 1939, issue of *Water Works & Sewerage*.

Sedimentation Factors

Sewage sedimentation is affected by a number of factors, such as

1. Physical shape of settling tanks.
2. Inlet and outlet arrangements.
3. Character of Sewage.
4. Strength of Sewage.
5. Degree of Solids removal required.

Shape of Settling Tanks

Opinions differ widely as to the most effective physical proportions to be employed in the design of settling tanks. Some tanks are square with cross-flow, others are square or round with center inlets and radial flow, while still others are rectangular, with longitudinal flow. The

question of settling tank shape is a controversial subject, influenced as it is by several types of commercial mechanical equipment. Such a discussion is outside the scope of this article. It is sufficient to state that the objective of a designer should be to achieve a *well-designed* settling tank having the proper capacity for the conditions to be satisfied, considering both the *sanitary* and the *economic* requirements. In order to anticipate the results his design will obtain, the designer must draw on his own experience, and on the experience of other engineers versed in this subject.

Inlet and Outlet Arrangements

In any settling tank, the design of inlet and outlet devices is very important in order to obtain the most effective use of the tank for settling purposes. In general, the shorter the distance between inlet and outlet, the more important becomes their effectiveness in uniformly distributing the flow through the tank. Thus, in a long tank, the inlet and outlet design, although important, is not so critical a factor as in the case of a shorter tank.

Many excellent inlet arrangements are in use, such as perforated cylinders, perforated baffles, submerged flow directed against the rear wall of a settling tank, and others. The use of overflow weirs for tank outlet is universal.

Character and Strength of Sewage

The accepted yardstick of sewage treatment plant and settling tank performance is the reduction in the 5-day biochemical oxygen demand of the sewage to a final standard of quality as determined by the oxygen requirements of the stream or lake into which the effluent is discharged. However, settling tank performance is more often expressed as "reduction in suspended solids." This is almost universally true in the smaller plants, where limited personnel does not permit frequent B.O.D. determinations. For any given sewage, a general, and sometimes fairly definite relation can be established between suspended solids and 5-day B.O.D.

It is often very difficult to obtain an accurate idea as to the average characteristics of the raw sewage from a municipality, particularly when the sewage is composed in part of trade wastes. Frequent sampling and analyses over a long period of time are required if a representative measure of the sewage characteristics is to be obtained.

At the Rahway Valley Sewage Treatment Plant, *daily* determinations for suspended solids have been made over a 2½-year period, or since the plant was placed into operation. On the other hand, determinations of 5-day B.O.D. have been made at 6-day intervals during a part of this period, and during the remainder of the period, at a frequency of 4 days per week. Therefore, a much more comprehensive record is available for suspended solids than is the case for 5-day B.O.D.

Daily raw sewage samples consisted of hourly samples composited each 24 hours without reference to variations in sewage flow. This has not affected accuracy, since the day and night flows at the Rahway Valley Plant have not varied sufficiently to influence sampling procedure.

The Rahway Valley sewage may be defined as a fairly fresh domestic sewage with a small proportion of non-interfering trade wastes. The raw sewage as it enters the settling tanks has been screened, and the heavier grit has been removed by a reasonably effective grit chamber. Wide variations have been noted in the raw sewage for both the 5-day B.O.D., and for the concentration of suspended solids. It is recognized that such variations are not universally characteristic, but they must certainly be present to a greater or lesser degree at any sewage treatment plant. The highest and lowest daily concentrations, and the highest and lowest monthly averages during the 2½-year period at the Rahway Valley Plant are as follows:

	B.O.D. P.p.m.	Suspended Solids P.p.m.
High Individual Daily	360	478
Low Individual Daily	43	50
High Monthly Average	286	239
Low Monthly Average	76	87

The averages of analyses of all samples taken over the entire 2½-year period are as follows:

	P.p.m.	Gm/cap/24 hr.
Suspended Solids	161	101
5-Day B.O.D.	135	85

These averages can of course be refined still further, and calculated for dry weather and wet weather flow conditions. For dry weather conditions they are as follows:

	P.p.m.	Gm/cap/24 hr.
Suspended Solids	207	111
5-Day B.O.D.	201	108

Degree of Solids Removal Required

The primary purpose of any sewage treatment plant is to remove organic matter from the sewage to such an extent that the receiving body of water can complete the purification process without detriment to the general public welfare.

In a plant using secondary treatment processes, it is obvious that the more efficient the primary settling tanks, the less is required of the secondary units in order to accomplish the desired results. But where the plant process consists principally of primary sedimentation, the performance required of the primary settling tanks will vary widely.

From an economic standpoint, the amount of settling, or in other words, the expected performance of settling tanks, should be balanced between the cost of the tanks and the amount of settling required. Since the performance of a settling tank for a given rate of flow is definitely related to the detention period, or "flowing-through" time, it is a matter of economy to make the detention period as short as is consistent with good performance. The question then arises: what is the proper performance for which a settling tank should be designed? Only a careful consideration of all engineering and economic factors can properly answer this question.

In the great majority of cases where primary treatment only is required, the degree of solids removal to be accomplished by the settling tanks should be predicated on the amount and quality of dilution provided for the plant effluent by the stream or lake into which it discharges. Therefore arbitrary design factors cannot be established, since one condition may require 60 per cent removal of suspended solids, while 35 per cent removal may be sufficient for another. Likewise, a well-designed tank may give 60 per cent removal of suspended solids for a 2½-hour detention period, while on the other hand, a poorly designed tank, of less advantageous shape or proportions, may show only 50 per cent removal of suspended solids for a 4-hour detention period. To use a common phrase, "the dog should wag the tail," instead of "the tail wags the dog."

Unfortunately, the designer very seldom has sufficient time available to accumulate a broad record of stream data over a considerable period of time. Short-period records covering only a few weeks are valuable only as a general guide, and may be very misleading unless the data period happens to embrace average conditions or protracted maximum conditions.

Where the project is sufficiently large, extensive preliminary work is usually undertaken, as was the case at Minneapolis-Saint Paul, where the technical staff of the Sanitary District accumulated a variety of stream data over a period of years, prior to the design of the sewage treatment plant. This is shown by the following excerpt from the report of the Minneapolis-Saint Paul Sanitary District for the years 1934–1935.

Sampling Intervals.—Ordinarily, in years past, single grap samples have been collected one or more days a week at stations from Camden to Hastings, and two or more days a month at stations from Prescott to Wabasha. The principal purpose in the collection of this data was to determine with a reasonable degree of certainty the general condition of the Mississippi River through the stretches affected by the discharge of sewage and industrial wastes from the metropolitan area of Minneapolis and St. Paul, together with changes brought about by the construction of dams. For this purpose, the data has been, generally speaking, satisfactory, and the expense of continuous collection of samples on a 24-hour basis would hardly have been justified, even if sufficient funds had been available.

However, with grab samples only, there was no measure of hourly variations during the day as may be brought about by a varying pollution of river discharge or algae effects upon the oxygen supply. It was considered advisable to establish the sampling on a

24-hour basis for a period of one year, both as a substantiation or check on the previous data, and to obtain more complete and detailed information on the river for use in degree of treatment studies, and as a better basis for comparison of river conditions before and after a treatment plant is placed in operation.

Accordingly, a program of sampling on a twenty-four hour basis was inaugurated about the middle of August, 1934, and is expected to continue until August, 1935, after which the sampling will again be conducted on a less intensive basis.

In any event, sufficient stream data should be available to permit the most judicious use of public funds in the abatement of stream pollution.

Theoretical Considerations

According to studies made by Schroepfer,[1] the velocity of subsidence of a settling particle in still water depends on

1. The size of the particle
2. The shape of the particle
3. Specific gravity of the particle
4. Temperature of the liquid mass
5. Concentration, or density of the particles

Ordinarily, in the analysis of sewage settling tank performance, no cognizance is taken of the size, shape, or specific gravity of the particles to be settled, except as they are affected by the "staleness" or "freshness" of the sewage. Obviously, a fresh sewage, or a sewage in which the solids have not been disintegrated by pumping or other violent agitation, will settle much more readily than a sewage in a stale or otherwise unfavorable condition.

Variations in the temperature of the liquid mass cause corresponding variations in the viscosity of the mass. The lower the temperature, the higher the viscosity, and vice versa. This explains in part why settling tank performances in the winter are not as high as during the warm summer months, even though conditions of flow and the characteristics of the sewage may be the same. Also, currents produced by changes in temperature tend to reduce the time required for the sewage to flow through the tank by inducing short-circuiting of flow, and thus decreasing the settling efficiency.

The concentration of the suspended matter in the sewage has been found to have a marked effect upon the reduction obtained in a given detention period. Babbitt and Schlenz [2] have worked out the following formula which indicates the relationship between detention period, concentration of settleable solids, and the reduction in suspended solids:

$$R = \frac{(D + 226)C}{3.72\left(C + \frac{216 - D}{4}\right)},$$

where

R = Reduction in settleable solids.
D = Detention period in minutes.
C = Concentration of solids in p.p.m.

The writer presents this formula to satisfy those who are interested in expressing sedimentation data in the form of an equation. No attempt has been made to verify this formula, or to derive a similar formula which will satisfy Rahway Valley conditions.

From a practical point of view, it would seem that the most important primary consideration in evaluating settling tank performance is the concentration of solids in the raw sewage. Other factors, such as physical design of the tank, relation between actual "flowing-through" period and theoretical detention period, and the characteristics of the sewage, may vary, but for similar sewages of equal concentrations, performances should be similar provided settling tanks are equally efficient.

Rahway Valley Settling Tanks

The settling tanks at the Rahway Valley Sewage Treatment Plant are three in number, rectangular in shape, each being 43 ft. 3 in. wide, 11 ft. 0 in. deep at the water line, and 202 ft. long from the inlet baffles to the effluent weirs. The combined water surface area of all the tanks is 25,000 sq. ft.

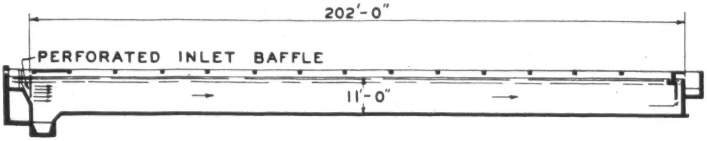


Fig. 1.—Rahway Valley settling tank.

The tanks are equipped with Link-Belt sludge collectors which scrape the settled solids along the tank floors at the rate of 2 ft. per min., and on their return flight move the floating solids and grease along the surface of the water to the effluent end of the tanks. Here the grease is removed manually into scum troughs in front of the effluent weirs.

Variations in Strength of Sewage

The raw sewage at Rahway Valley varies from day to day, month to month, and even from year to year. The changes in strength of sewage from day to day are not as a rule abrupt unless increased flow due to precipitation causes either a lowering of the solids content by dilution, or a temporary increase by reason of the washing down of excessive quantities of grit and solids deposited in the sewers.

In general, the higher the rate of sewage flow, the lower becomes the concentration of suspended solids, and conversely, as the flow decreases,

the suspended solids increase. Thus in dry weather periods, the strength of sewage is high, and during the wet weather periods, the opposite is true.

This relation is shown graphically by Fig. 2, in which the average daily sewage flows in m.g.d., and the average p.p.m. suspended solids in the raw sewage are indicated for each month from March, 1938 to February, 1940.

The relation between flow and strength of sewage is also shown by a different method in Fig. 3, in which curves are drawn showing the concentration of suspended solids according to daily sewage flows, and according to the percentages which the daily sewage flows are of the

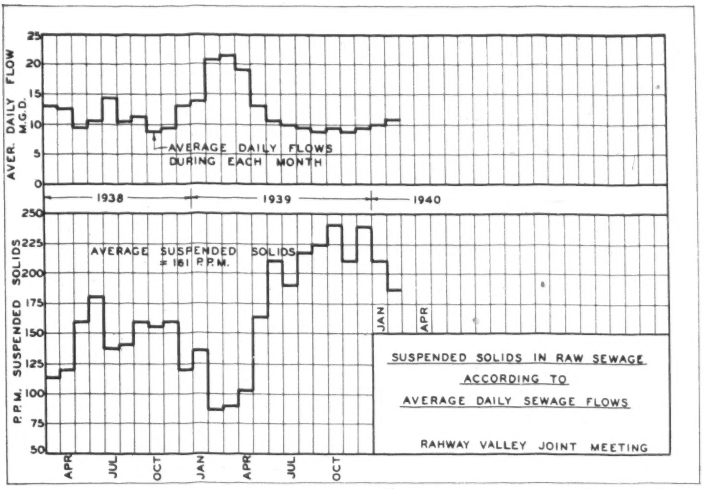


FIG. 2.

average dry weather flow. The records of dry weather sewage flows have been examined for several protracted dry spells, and the average has been found to be approximately 8.65 m.g.d.

The variations in strength of sewage as shown by Fig. 2 and Fig. 3 illustrate the statement previously made to the effect that long term observations are required to obtain a true measure of raw sewage characteristics.

SEWAGE FLOWS VS SETTLING EFFICIENCIES

It has also been observed at the Rahway Valley Plant that as sewage flows increase, settling tank efficiencies as measured by the reduction in suspended solids decrease. This is easily explained, since the

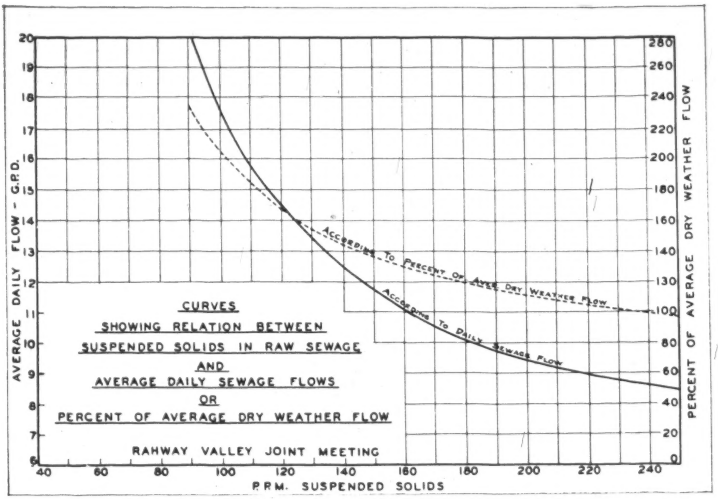

AVERAGE DAILY FLOW - G.P.D.
PERCENT OF AVERAGE DRY WEATHER FLOW
ACCORDING TO PERCENT OF AVER. DRY WEATHER FLOW
ACCORDING TO DAILY SEWAGE FLOW
CURVES
SHOWING RELATION BETWEEN
SUSPENDED SOLIDS IN RAW SEWAGE
AND
AVERAGE DAILY SEWAGE FLOWS
OR
PERCENT OF AVERAGE DRY WEATHER FLOW
RAHWAY VALLEY JOINT MEETING
P.P.M. SUSPENDED SOLIDS

FIG. 3.

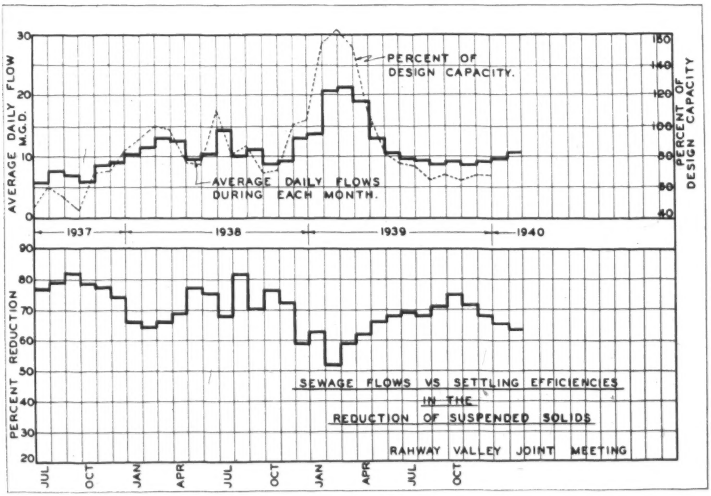

AVERAGE DAILY FLOW M.G.D.
PERCENT OF DESIGN CAPACITY
AVERAGE DAILY FLOWS DURING EACH MONTH.
1937
1938
1939
1940
PERCENT REDUCTION
SEWAGE FLOWS VS SETTLING EFFICIENCIES IN THE REDUCTION OF SUSPENDED SOLIDS
RAHWAY VALLEY JOINT MEETING
JUL
OCT
JAN
APR
JUL
OCT
JAN
APR
JUL
OCT

FIG. 4.

higher the rate of flow, the shorter the "flowing-through" period in the settling tanks. Figure 4 not only illustrates the effect of sewage flow upon settling efficiency, but also shows the relation between settling efficiency and the per cent of theoretical design capacity. Thus, the Rahway Valley Tanks, which were designed for a volumetric displacement period of 4 hours for average flow, show excellent reductions in suspended solids when operating from 45 per cent to 70 per cent of design capacity, good reductions between 70 per cent and 100 per cent, and progressively poorer reductions above 100 per cent.

Sedimentation Curves

As has been previously expressed, a definite relation exists in a settling tank between strength of sewage, detention period, and reduction in suspended solids. A considerable amount of data is required throughout the entire range of detention periods in question. In order to obtain sufficient information, our records of daily suspended solids

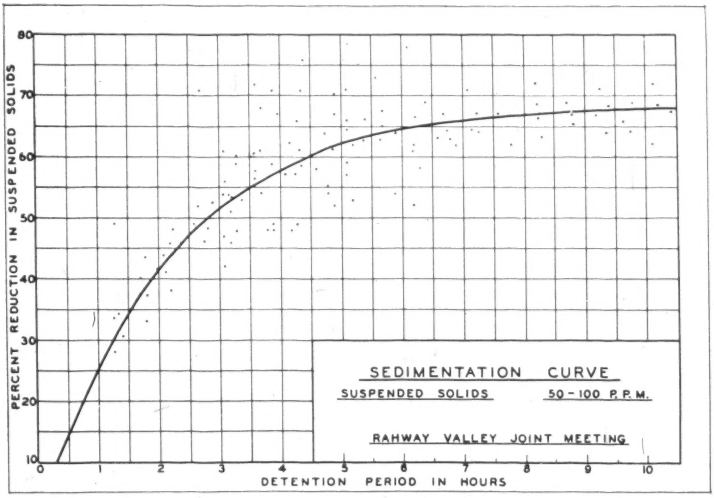


Fig. 5.

removal were supplemented during the summer of 1939 with a large number of determinations of results of controlled detention period through one of the settling tanks. All of the data thus made available was tabulated according to the strengths of raw sewage, and then plotted into the curves shown in Figs. 5, 6, 7, 8, and 9. No attempt was made to select favorable data, or to "sift out" unfavorable data.

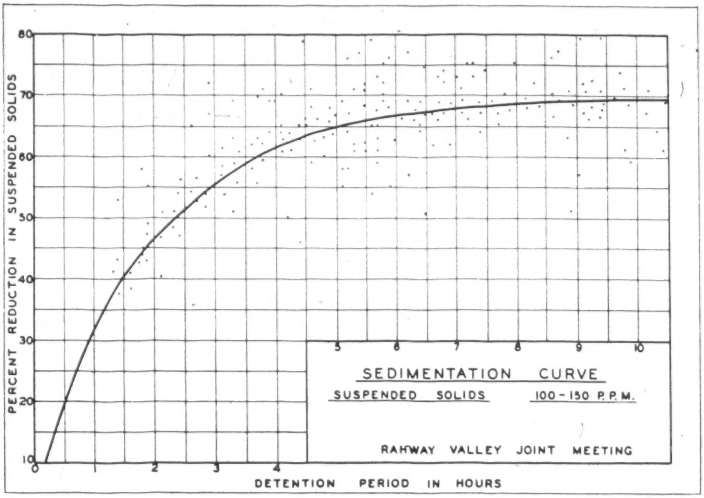

PERCENT REDUCTION IN SUSPENDED SOLIDS
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
DETENTION PERIOD IN HOURS
SEDIMENTATION CURVE
SUSPENDED SOLIDS 100 - 150 P.P.M.
RAHWAY VALLEY JOINT MEETING

FIG. 6.

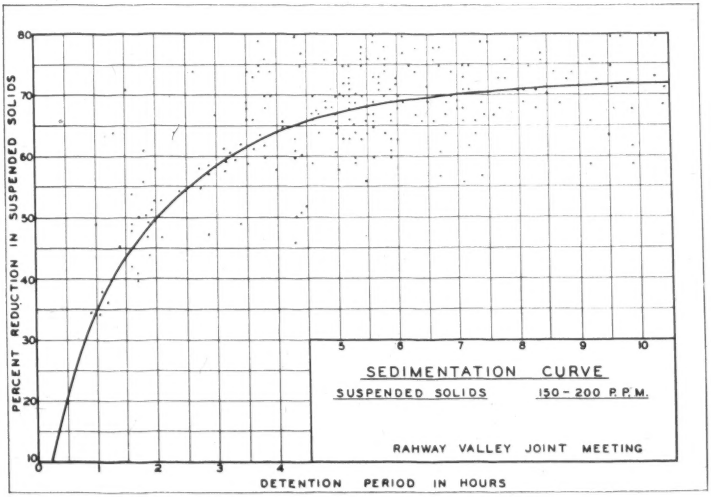

PERCENT REDUCTION IN SUSPENDED SOLIDS
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
DETENTION PERIOD IN HOURS
SEDIMENTATION CURVE
SUSPENDED SOLIDS 150 - 200 P.P.M.
RAHWAY VALLEY JOINT MEETING

FIG. 7.

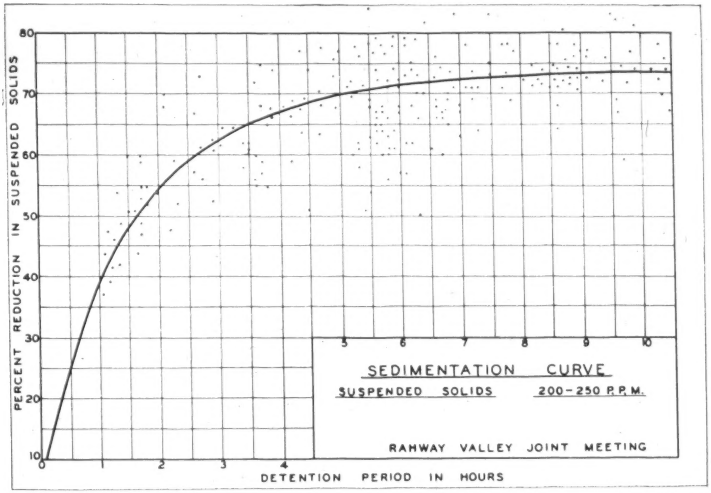

PERCENT REDUCTION IN SUSPENDED SOLIDS
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
DETENTION PERIOD IN HOURS
SEDIMENTATION CURVE
SUSPENDED SOLIDS 200-250 P.P.M.
RAHWAY VALLEY JOINT MEETING

FIG. 8.

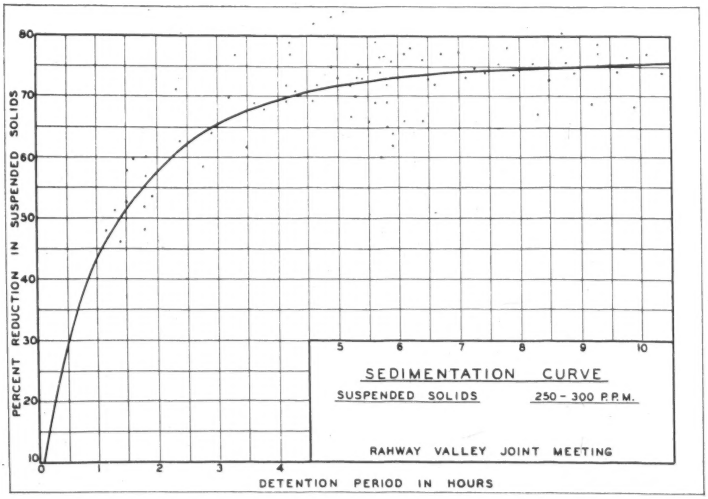

PERCENT REDUCTION IN SUSPENDED SOLIDS
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
DETENTION PERIOD IN HOURS
SEDIMENTATION CURVE
SUSPENDED SOLIDS 250-300 P.P.M.
RAHWAY VALLEY JOINT MEETING

FIG. 9.

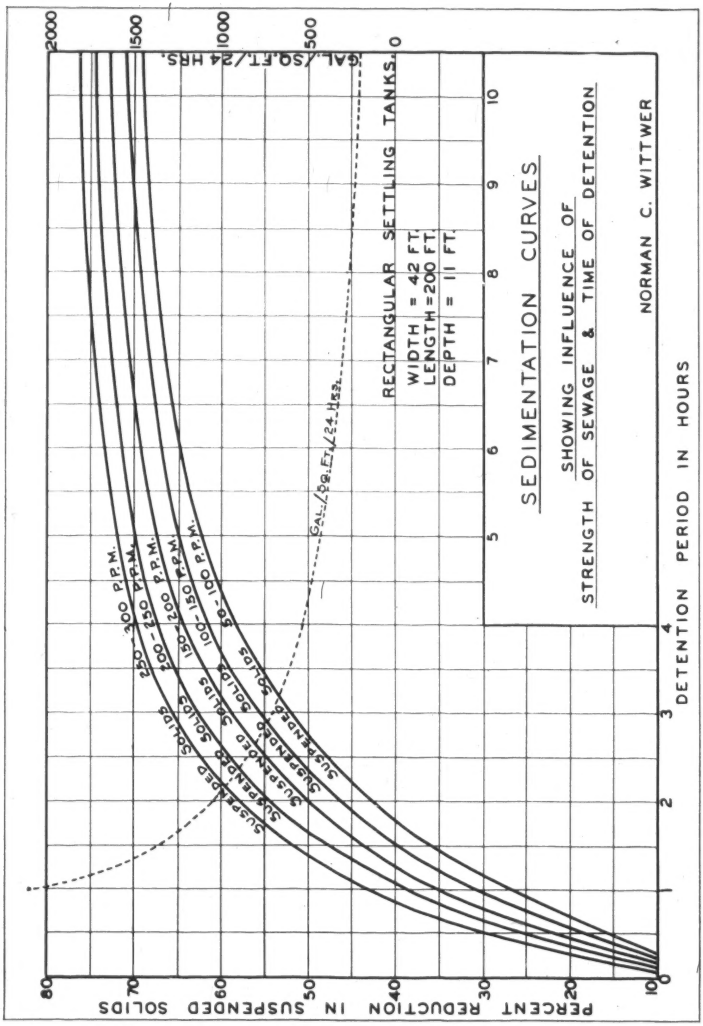

SEDIMENTATION CURVES
SHOWING INFLUENCE OF
STRENGTH OF SEWAGE & TIME OF DETENTION
RECTANGULAR SETTLING TANKS.
WIDTH = 42 FT.
LENGTH = 200 FT.
DEPTH = 11 FT.
NORMAN C. WITTWER
PERCENT REDUCTION IN SUSPENDED SOLIDS
DETENTION PERIOD IN HOURS
GAL./SQ.FT./24 HRS.
GAL./SQ.FT./24 HRS.
SUSPENDED SOLIDS 250 - 300 P.P.M.
SUSPENDED SOLIDS 200 - 250 P.P.M.
SUSPENDED SOLIDS 150 - 200 P.P.M.
SUSPENDED SOLIDS 100 - 150 P.P.M.
SUSPENDED SOLIDS 50 - 100 P.P.M.

Fig. 10.

All suspended solids determinations were made on 24-hour hourly-composited samples. Detention periods were computed volumetrically, with no allowance for short-circuiting of flow.

The following records were obtained for the several ranges of solids concentration shown on the curves.

Suspended Solids P.p.m.	Number of Determinations
50–100	126
100–150	186
150–200	227
200–250	221
250–300	82

Composite Curves

The curves shown by Figs. 5 to 9 inclusive were transferred to a single sheet, Fig. 10. This shows at a glance the Rahway Valley Settling Tank performance for a definite strength of sewage at a given theoretical detention period.

For convenience, a supplementary curve has been plotted which will enable selection of tank performances according to gallons of raw sewage per square foot of water surface per 24 hours. In effect, this curve converts the rate of flow in gallons per square foot per 24 hours to detention period in hours. It can be used as shown by the following example.

> If the probable percent reduction in suspended solids is required for a 175 p.p.m. raw sewage flowing through the settling tank at the rate of 750 gallons per square foot per day, enter the curve from 750 on the scale at the right, intersecting the dotted curve of gal./sq./ft./24 hrs., and then go vertically to the 150–200 p.p.m. suspended solids curve, thus giving the per cent reduction of 58 per cent.

The curves shown in Fig. 10 are very interesting, and will be helpful in properly interpreting and evaluating future plant performances. Although these curves apply particularly to the Rahway Valley tanks, the general relationship will hold true for any settling tank, and is applicable in principle to all settling tank design.

Summary and Conclusions

1. The observations and conclusions drawn from the Rahway Valley experience were derived from comprehensive records of settling tank performance over a 2½-year period. A total of 1688 suspended solids determinations were made on 24-hour hourly composited samples, these determinations being equally divided between the settling tank influent and effluent.

2. Concentration of suspended solids in raw sewage varies with the rate of flow.

3. The performance of a sewage settling tank varies with the flow.

4. For a given rate of flow, the performance of a sewage settling tank varies with the concentration of suspended solids in the raw sewage.

5. Many analyses and long term observation are required to obtain a true measure of raw sewage characteristics.

6. Many observations over a considerable period of time are required to properly evaluate the performance of a sewage settling tank.

References

1. George S. Schroepfer, THIS JOURNAL, 5, 209 (March, 1933).
2. H. E. Babbitt and Harry Schlenz, "Results of Sewage Treatment," University of Illinois, *Bulletin* 198 (1929).

OIL AND GREASE IN SEWAGE

By W. S. Mahlie

Chemist-in-Charge, Water and Sewage Purification, Fort Worth, Texas

One phase of sewage treatment which has not received the attention it should, is that of oil and grease content and its effect on treatment. While the presence of grease has been recognized for a long time, its importance in treatment has not been stressed a great deal and it is only within the last few years that some study has been given to its effects.

Grease occurs in surprisingly larger quantities than one usually suspects, and its effects are probably more far-reaching than one cares to admit. The following several quotations are quite pertinent.

Geo. W. Fuller [1] said "and more attention is being given to methods of removal of grease and scum as a distinct rather than incidental operation."

Charles Gilman Hyde [2] points out "the need for a more effective removal of greases and oils so deadly to activated sludge plants."

Harrison P. Eddy in a paper read before the *A. S. C. E.* Sanitary Engineering Division in New York, January, 1935, called attention to the ill effects and plant appearances (especially activated sludge plants) caused by oils and greases. Greeley [3] also comments on grease removal in designs of new plants.

Dr. Hermann Bach [4] says "as the degreasing of sewage in a preliminary disposal stage is highly beneficial for every kind of afterwards treatment of the liquid portion as well as of the sludge . . . the newest application of chlorine . . . , may later on be registered as one of the most important steps forward in sewage and wastes purification progress."

In view of the tendency in recent years to introduce garbage into our sewer systems, it seems appropriate to call attention to the problem.

Keefer [5] at Baltimore shows the grease content of garbage to be from 13.5 per cent to 35.5 per cent, while Bloodgood [6] at Indianapolis found 24.06 per cent and Welch [7] at Flint, Michigan, found 17.1 per cent. Babbitt [8] says putting the entire garbage load of a community on the sewage plant digesters, will more than double the grease load. Downes [9] gives his experience and says garbage gave trouble and resulted in unsightly grease covered settling basins and clogged filter nozzles.

While many cities have ordinances prohibiting the discharge of wastes containing oil, gasoline, grease, tar, etc. into the sanitary sewers, not many of them are specific as to the amount which may be present, for it must be realized that practically all wastes contain some grease. It is to be hoped that in the near future ordinances will specifically state certain maximum limits, not only for grease but for all constituents.

Los Angeles, for instance limits the grease to 600 p.p.m., while a sanitary district in Massachusetts sets 300 p.p.m. as the limit.

Within the last few years an active interest has developed in the abatement of stream pollution, and as many industries now discharge their wastes into streams without or with only a minimum of treatment, they are now demanding that the cities permit them to run their wastes to the municipal treatment plant, it behooves the city authorities to study the character of these wastes. Since grease is one of the offending constituents most commonly found in such wastes it is hoped that the following will be of some interest.

The Effect of Oil and Grease in Sewage

In discussing the effect of grease in sewage three factors may be considered: *First:* The effect on the sewer system, *Second:* The effect on water courses receiving the sewage, *Third:* The effect on plant operation.

The Effect on Sewer Systems. (*a*) *Explosions and Fires.*—The effect of gasoline, garage wastes, and other light oils, such as kerosene, are too obvious to require much comment, other than that owing to their high vapor pressures, explosive mixtures are formed and if confined, will when ignited, explode with serious consequences. Explosions usually take place in the sewers although there are cases on record where the explosion took place in the pumping station, for example the occurrence at East Boston pumping station on June 1, 1914, when six men were killed and three others injured.[10] The danger from explosions in sewers has been pointed out by a number of investigators. Skinner [11] mentions an instance of explosion recently from oily wastes. In the '80's at Rochester, he recalls that an oil company ran a naphtha line under the Pennsylvania Railroad tracks. The heavy vibration caused a break in the line, from which the naphtha leaked into a sewer and finally at a distance of one and one-half miles down stream the sewer "blew up." Two stone mills were burned and two men killed.

Knowlton [12] reports an explosion at Los Angeles in the Slauson outfall sewer. Gasoline vapors were ignited by an asphalt heater on the street. Thirty man-hole covers were blown into the air from two to twenty-five feet. The covers weighed 220 pounds each and several of them were broken by the impact. Fortunately no persons were injured although the street was full of traffic.

At Montreal [13] on November 30, 1932, an explosion, presumably caused by gasoline, took place, injuring thirty persons. Killam and Klegerman [14] point out the increasing number of explosions in sewers due to gasoline. Ripperger [15] in studying eighty-seven sewer explosions in Germany extending back as far as forty years, found that gasoline was responsible in fifty-one cases.

Fales [16] also points out the danger from gasoline explosions, and cites the explosion at Newburgh, N. Y., where one person was killed and twenty more seriously injured, along with an estimated property dam-

age at $200,000 to $300,000. While it was not definitely proven that gasoline caused the explosion, it is mentioned that it easily could have been responsible. He also mentions an explosion at Springfield, Mass., in December, 1934, due to gasoline escape into the sewer from nearby gasoline tanks and pipes.

In connection with explosions in sewers it might be well to point out that according to the U. S. Bureau of Mines, one and one-half per cent of gasoline vapor in air may be explosive. One gallon of gasoline produces 32 cu. ft. of vapor at ordinary temperature and pressure. If 1.5 per cent is taken as the low explosive limit, one gallon of gasoline would result in 2,130 cu. ft. of explosive mixture in a sewer.

At Middletown, N. Y.,[17] burning gasoline followed the sewage into the building but no serious damage resulted. A fire of similar origin occurred when the plant was first put in operation in 1930.

Sperry[18] reports a serious fire at Aurora, Ill., from accumulated oils, gasoline and grease skimmings which had been stored in a "grease bin."

(*b*) *Sewer Stoppages and Grease Balls.*—Anyone who has ever opened up a "stopped up" kitchen sink can readily visualize the effect of grease on other sewer lines. The effect is probably more noticeable on small than on large sewers. The grease sticks to the sides of the sewer, floating particles of other materials such as match sticks, become enmeshed and the deposit increases until it is sufficient to seriously impair the normal flow of sewage. Eventually portions slough off and completely stop up the line.

We have analyzed a sample of this so-called pipe grease which is as follows:

Volatile Matter	93.51%
Ash	6.49

The volatile matter consisted of

Grease and soap	92.13%

The ash consisted of

Silica	2.19%
Iron and aluminum oxides	1.29
Calcium oxide	2.11
Magnesium oxide	0.14
Undetermined	0.76

At other times small portions of the grease will break off and during their passage through the lines to the point of discharge they will be churned around and appear as the familiar "grease balls." These can commonly be seen at various points in the grit chambers, Imhoff and primary settling tanks.

The composition of these grease balls has been given by Wright[19] as: 25 to 45 per cent free fat (dry basis), 30 to 47 per cent soap fat (dry basis), 7.6 to 13.4 per cent lime as $CaCO_3$ (dry basis).

Heisig[20] has reported trouble at Milwaukee with sewer line stoppages caused by grease.

While we have had the usual number of grease stoppages in Fort Worth, during September, 1934, we had an unusually large amount of grease balls reach our plant, which were arrested in the grit chamber. The amount received varied from three to twelve barrels daily, the balls ranging in size from 1 in. to 8 in. in diameter. We had various amounts of these grease balls through the month of January, 1935. During this time we were searching for the source of the grease, and it was finally discovered by the stopping up of an 18 in. sewer leading from a small meat canning plant. About eight truck loads of grease were removed from the line. This canning plant had been handling "Government killed" mutton and no attempts were made to save the grease and tallow. The easiest way of disposal naturally was through the sewer. It was estimated that about $50 worth of grease had been lost daily. Later a grease catch-basin was installed and the grease recovered.

The Effect on Water Course Receiving the Sewage.—If the sewage is only partly or not treated at all before final disposal into a water course, there are some ill-effects which should be mentioned.

Sierp [21] gives expression to this as follows "Small quantities of oil can cover large surfaces, and shut off the oxygen and prevent natural purification. Rivers cannot purify or break down the oils. They (oils) impart taste and odor to drinking water when the river is used as a source of supply. They leave deposits on the sloping shores. Fish spawning places are damaged, and fish food is injured. When the water or sewage is used for irrigation, oil films fill up the pores of the soil."

Wright [19] reports that grease balls were very annoying to the people using the beaches for recreation at Salem, Mass. He also mentions grease balls being found as far as 66 miles away from Boston Harbor.

The Effect of Grease on Plant Operation.—The deleterious effects of grease on plant operation have been stressed by a numbr of writers such as Hansen,[22] Jones,[23] Batty,[24] Oeming,[25] Geyer,[26] Sierp,[21] and numerous others.

These ill effects may be listed as follows: (*a*) Blinding screens, (*b*) Unsightly accumulations on walls, (*c*) Interference with Imhoff tank functions, (*d*) Grease and scum formation, (*e*) Odors, (*f*) Interference with activated sludge, (*g*) Clogging of filters, nozzles, and sand beds, (*h*) Paint destruction, and (*i*) Interference with digestion processes.

(*a*) *Blinding Screens.*—Parkes [27] attributes grease as the cause of blinding Dorr screens at Los Angeles. Van Kleeck [28] blames grease in the raw sewage for blinding of his filter cloths. Eddy [29] comments on the clogging of fine screens by grease.

(*b*) *Accumulations on Walls.*—Floating oils and grease when passed through settling tanks tend to stick to the side walls and produce unsightly masses at the high water line. Hyde,[30] Eddy,[29] and Hardenbergh [31] have called attention to this. Cameron [32] reports trouble at Fostoria, Ohio, from grease building up on floats and float pipes causing the control floats on the wet well to stick. Sierp [21] also calls atten-

tion to the formation of unsightly masses on the walls and surfaces by grease.

Analysis of such accumulation on the walls of the primary tanks at Fort Worth shows it to contain 56.94 per cent grease of which 84.06 per cent is saponifiable, while the accumulation on the walls of the dosing tanks at the high water line shows a grease content of 37.32 per cent of which 78.69 per cent is saponifiable.

(*c*) *Interference with Imhoff Tanks.*—Skinner [33] reports oil from a leaking tank containing road oil finally found its way into the sewers and thence to the Imhoff tanks at the Brighton plant, Rochester, N. Y., putting them out of commission for six months. This interference with Imhoff tank operation has also been mentioned by Eddy.[29]

Cleland [34] says that oil stopped all digestion in Imhoff tanks at State College, Pa. Sierp [21] holds grease responsible for interfering with digestion, while Geyer [35] says grease increases the foaming.

(*d*) *Grease and Scum Formation.*—Scum in sewage treatment is probably the greatest worry of the plant operator. Whether it is in the Imhoff or primary tanks or whether it is in the digester, it constitutes one, if not the major operating problems. This is primarily due to the absence of facilities for handling it.

In the "Manual of Engineering Practice," No. 2, *A. S. C. E.*, 1928, scum is defined as "A mass of sewage solids, buoyed up by entrained gas, grease, or other substance which floats at the surface of sewage." Gilcreas [36] describes the role of grease in scum formation nicely. He says "An excessive amount of grease will form a nucleus for the accumulation of scum. Because of its adhesive character and because it collects on the surface it may enmesh other floating particles, paper, sticks, straw and sewage solids and form a hard tight scum which often may grow to several inches or feet in thickness and prevent normal digestion in tanks or in other parts of the plant. Such scum is difficult to remove and creates a serious problem."

Walraven [37] at Springfield, Ill., found that his scum troubles were alleviated by the installation of a grease basin ahead of the settling tanks. Cameron [32] at Fostoria, says the main trouble caused by oils and greases was the excessive amount of skimming required at the primary tanks. Haseltine [38] names grease as one of the causes for excessive scum formation at Topeka, Kansas. Bach [39] also attributes excessive scum formation to oils and grease.

Eddy [40] in his "Investigation of Difference in Behaviour of Imhoff Tanks" says the insoluble soaps may favor the formation of scum.

Rudolfs [41] in his experiments on high and low temperature digestion showed that crankcase oil increased the scum formation in the digesters and also added to the digestion time.

(*e*) *Odors.*—Excessive grease accumulation has been blamed by Lanphear [42] as being the cause of odors from Imhoff tanks.

Ryan [43] says "another class of compounds which give off odors of an offensive character are the fats. Fats become rancid in two ways. The oxidation type of decomposition causes the fat to become rancid

and give off a tallowy odor; the hydrolytic type causes the fat to break down to fatty acids of a volatile nature such as acrylic, butyric, valeric, caproic and caprylic acids. These are commonly spoken of as 'goat acids.' "

Jones [44] mentions greases as a source of odors, and cautions that the skimmed-off materials quickly become putrid, giving off nauseating and penetrating odors. Cameron [45] reports odors from accumulated grease skimmings at Erie, Pa., and that the use of chlorine remedied the situation. Tatlock [46] also blames grease for odors around a sewage plant.

(*f*) *Interference with Activated Sludge.*—The detrimental effect of grease on activated sludge processes has been pointed out by Eddy,[20] Oeming [25] and Sierp.[21]

Hyde [47] says "The presence of mineral oils in aeration tanks of the activated sludge process has long been recognized, particularly in England, as a decided detriment. The high surface tension of oily sewages reduces the efficiency of aeration. Moreover, the presence of mineral oils in considerable quantities may have a toxic effect on the biological organisms involved and may seriously interfere with their proper functioning. For years past, in English plants utilizing mechanical types of aeration, such as the Simplex, the Sheffield paddle, and the like, castor oil rather than a mineral oil have been employed for the lubrication of the mechanisms. Mineral oils may and probably sometimes actually do have an inhibiting effect upon the biological organisms associated with trickling and intermittent sand filters."

Stanley [48] reported that oils prevented building up of activated sludge at San Antonio, Texas. Heisig and Brower [49] state that at Milwaukee their purification efficiencies have been lowered by excessive amounts of oil and grease in the sewage. Wisely [50] quotes "Large quantities of oil and grease seem to coat the flocs and do not give the organisms sufficient contact time with the sewage."

Bach [51] says mineral oils accentuate bulking in the submerged aerocontact filters. Haseltine [52] says grease seriously upsets the operation of the Topeka, Kansas, activated sludge plant.

(*g*) *Clogging of Filters, Nozzles and Sand Beds.*—The grease accumulating at the flow lines of settling tanks or dosing tanks may sometimes break off and cause stoppage in trickling filter nozzles, and jets of distributors. Kratz [53] lists grease as one of the principal causes of nozzle stoppage at Baltimore. Waldron [54] holds grease responsible for pooling in the filters at Hamilton, N. Y., making it necessary to remove the top three feet of stone. Cameron [32] says that grease was responsible for cleaning as many as twenty-five per cent of the total filter nozzles daily.

Hyde [47] lists grease as the cause of clogging of sand filters, and Coburn [55] blames grease as being responsible for the clogging of sand filters at Hudson, Mass.

(*h*) *Paint Destruction.*—McClenahan [56] in a study of paints for the sewage plants of the Sanitary District of Chicago says "The most de-

structive agent to paints submerged in sewage was a tar-like accumulation of oil and grease coming from the flowing sewage."

Corrao [57] quotes "When oils or greases become emulsified with water they very effectively destroy the paints they come in contact with. They dissolve the vehicle and make it susceptible to mechanical damage thereby exposing the steel to attack by water, hydrogen sulphide and other destructive agents."

(*i*) *Interference with Sludge Digestion.*—Interference with digestion processes has been pointed out by Coburn [55] and by Riddick.[58] Nevin found that greases from scum produced an acid reaction and impaired digestion at Philadelphia.

Rudolfs [60] in his experiments found that when waste oil was added to sludge in excess of 25 c.c. per liter, the rate of digestion was slowed down considerably. He also found that one per cent by volume of gasoline doubled the digestion time for fresh solids.[61]

Heukelekian [62] says fats determine the rate and extent of sludge digestion to a great measure. Fatty acids may cause the pH to drop from 6.4 to 6.8 down to 5.2 to 6.0. (In sludge digestion processes it must be remembered there is a great difference in activity between saponifiable and unsaponifiable oils which are discussed later.)

Origin of Grease in Sewage

Grease in sewage originates from several sources. (*1*) *From feces.* According to Stitt, one gram of normal dried feces contains 225 mg. total fat or 22.5 per cent. This fat is composed of:

Total fatty acids	86.0 mg. or 37.9 per cent of the fat.
Total soap	74.7 mg. or 33.4 per cent of the fat.
Neutral fat	64.4 mg. or 28.5 per cent of the fat.

Nishihara [63] finds human feces to contain only 4.4 per cent fats based on dry material. Such wide variations are no doubt due to the difference between a Japanese and an American diet.

(*2*) *Kitchen slops, garbage and waste waters.*—These wastes contain not only the unused fats from food stuffs, but also soaps, both the sodium soaps and the calcium and magnesium soaps resulting from the reactions with the hardness of the water. (Fat in garbage has been mentioned previously.)

(*3*) *Manufacturing wastes.*—Manufacturing wastes may contain excessive quantities of grease, particularly those coming from packing houses, canning plants, dairies, wool processing plants, oil refineries and numerous others.

(*4*) *Garage and automobile washing plants.*—Garages and automobile washing plants, although in most instances are required to trap out their oils and greases, nevertheless allow considerable quantities to escape them, chiefly through lack of attention.

TABLE I.—*Grease Content of Various Sewages*

City	Type of Sewage	Grease, P.p.m.
Annandale, N. J.	Boys Reformatory.	200
Alliance, Ohio	Separate. No trade wastes.	37
Atlanta, Ga.	Peach Tree Plant. 62% combined. 38% separate.	83
Atlanta, Ga.	Intrenchment Plant. No trade wastes.	104
Baltimore, Md.	Separate. Small amount trade wastes.	40
Boston, Mass.		37
Canton, Ohio	Separate. No trade wastes.	62
Chicago, Ill.	Combined.	23
Columbus, Ohio	Combined and separate. Some trade wastes.	100
Columbus, Ohio	Combined.	27
Fitchburg, Mass.	Separate and combined. Some paper and mill wastes.	63
Flint, Mich.		48
Gloversville, N. Y.	Combined.	48
Glen Gardner, N. J.	Tuberculosis Sanitarium.	50
Greystone Park, N. J.	Insane Asylum.	46
Hillsdale, N. J.	State Hospital. Separate domestic.	43
Hillsdale, N. J.	Insane Asylum.	48
Houston, Texas	North Side Plant. Separate, some oil.	39
Houston, Texas	Southside Plant. Separate.	36
Indianapolis, Ind.		39
Jamesburg, N. J.	Boys Correctional School.	145
Lancaster, Pa.		19 to 43
Lexington, Ky.	Separate. No trade wastes.	58
Los Angeles, Cal.	Packinghouse wastes.	400
Los Angeles, Cal.	Waste from sardine cannery.	7,940
Madison, Wis.	Packinghouse wastes.	336
Marlboro, N. J.	Separate.	43
Milwaukee, Wis.		52
N. J. Health Dept.	Laundry wastes (average sample).	1,408
Oaklawn, N. J.	Laundry wastes.	1,408
Philadelphia, Pa.	Combined.	52
Reading, Pa.	Separate. Some trade wastes.	25
Rochester, N. Y.	Brighton Plant. Separate. No trade wastes.	16
Rochester, N. Y.	Irondequoit Plant. Combined. No trade wastes.	34
Salinas, Cal.		340
San Francisco, Cal.	Golden Gate Park.	38
San Marcos, Texas	Separate. No trade wastes.	18
Sherman, Texas	Separate. No trade wastes.	69
Sioux Falls, S. D.	Domestic sewage.	85
Sioux Falls, S. D.	Primary tank effluent.	63
Sioux Falls, S. D.	Packinghouse wastes.	368
Sioux Falls, S. D.	Packinghouse wastes, screened and settled.	251
Skillman, N. J.	Epileptic Sanitarium.	54
Topeka, Kans.	Domestic.	60
Topeka Kans.	Combined with packinghouse wastes.	116
Topeka, Kans.	Packinghouse wastes.	1,481
Bradford, ENGLAND	Wool treating wastes. City included.	890
Bradford, ENGLAND	Wool treating wastes. Average.	8,650
	Maximum.	25,800
	Minimum	3,000

Quantity of Grease in Raw Sewage

The quantity of grease in raw sewage varies considerably, the variations being usually the result of trade wastes entering the sewers. Packinghouses contribute a rather large quantity, and wool scouring wastes are particularly bad in this respect.

Gilcreas[64] says grease should not be greater than 25 p.p.m., while U. S. P. H. S. *Bulletin* 132, gives the average of sixteen cities as 53 p.p.m., which according to Eddy[65] is equivalent to 0.05 pound per capita per day. Bloodgood[66] estimates the grease at 29.1 grams or .064 pounds per capita per day for Indianapolis in 1936, while for 1938[67] he reports 37.2 grams or .082 pounds per capita per day.

Wright gives the average for Massachusetts sewages at 97 p.p.m.

Table I shows the grease content of a number of sewages.

In a study made in 1921 at Fort Worth, it was found (as would be expected) that the grease content of the sewage varied throughout the day and night as shown in Table II below.

Table II.—*Grease Content of Domestic Sewage*
Fort Worth, Texas (1921)

No. of Samples	Time Taken	Grease, P.p.m.
34	From 3 A.M. to 6 A.M.	13
10	From 9 A.M. to 12 Noon	141
9	From 3 P.M. to 6 P.M.	145
28	From 9 P.M. to 12 M.N.	74
Average of all samples		64

The same thing was true for packinghouse wastes. From 3 A.M. to 4 A.M. the grease content of the raw wastes was 49 p.p.m.; from 2 P.M. to 4 P.M. it was 365 p.p.m. and from 9 P.M. to 11 P.M. it was 94 p.p.m.

Moreover it was also found that variations occurred according to the days of the week, as will be seen from the following.

Table III.—*Grease Content of Fort Worth Sewage. Mixture of Domestic and Settled Packing House Wastes Received at Treatment Plant*
(1939)

	Grease, P.p.m.
Sunday	103
Monday	119
Tuesday	174
Wednesday	146
Thursday	168
Friday	117
Saturday	No Samples
Average	143

The treated (screened and settled) packinghouse wastes also showed variations throughout the week as follows:

Monday	131 p.p.m. grease
Tuesday	190 p.p.m. grease
Wednesday	391 p.p.m. grease
Thursday	275 p.p.m. grease
Friday	176 p.p.m. grease
Saturday	313 p.p.m. grease

Composition and Nature of Grease

According to the "Standard Methods of Water and Sewage Analysis," grease is defined as "fats, waxes, free fatty acids, calcium and magnesium soaps, mineral oils and other non-fat substances." Grease as referred to in sewage may be made up of all sorts of combinations of the preceding. We generally refer to the liquid portions as oil, and the solid part as grease. The term "fat" is also used to a great extent, but it generally applies to substances of animal or vegetable origin.

The true fats, chemically speaking, are glyceryl esters, that is they are glycerine $C_3H_5(OH)_3$ in which the hydroxyl groups (OH) have been replaced with fatty acid radicals, as indicated by the reaction below, using stearic acid as an example.

$$\underset{\text{glycerine}}{C_3H_5(OH)_3} + 3\underset{\text{stearic acid}}{C_{17}H_{35}COOH} = \underset{\substack{\text{tri-stearin}\\(\text{a glyceryl ester})}}{C_3H_5(C_{17}H_{35}COO)_3} + \underset{\text{water}}{3H_2O}$$

The glyceryl esters of stearic, palmitic and oleic acids constitute the main bulk of the fats and oils in food and of body or animal fat.

When a glyceryl ester such as tri-stearin is heated with an alkali such as sodium or potassium hydroxide, a reaction known as saponification takes place and the resultant product is a soap.

$$\underset{\text{tri-stearin}}{C_3H_5(C_{17}H_{35}COO)_3} + 3\underset{\substack{\text{sodium}\\\text{hydroxide}}}{NaOH} = \underset{\text{glycerine}}{C_3H_5(OH)_3} + 3\underset{\substack{\text{sodium stearate}\\(\text{a soap})}}{C_{17}H_{35}COONa}$$

By this action the glycerine is again liberated, and the acid radical combines with the sodium hydroxide to produce sodium stearate, a soap.

If the resulting soap is now allowed to come in contact with calcium or magnesium salts, such as constitute the hardness of water, another reaction takes place.

$$2\underset{\substack{\text{sodium}\\\text{stearate}}}{C_{17}H_{35}COONa} + \underset{\substack{\text{calcium}\\\text{sulfate}}}{CaSO_4} = \underset{\substack{\text{calcium}\\\text{stearate}}}{(C_{17}H_{35}COO)_2Ca} + \underset{\substack{\text{sodium}\\\text{sulfate}}}{Na_2SO_4}$$

The water is now softened due to the removal of the calcium salts in the form of insoluble calcium stearate.

Table IV shows the more common organic acids which are found in the edible fats and oils, combined with glycerine to form glyceryl esters as previously explained. Some of these acids may exist in part as free acids along with the glyceryl esters. In such condition they impart rancidity to the products.

TABLE IV.—*Organic Acids Found in the Edible Fats and Oils*

Acid	Formula	Molecular Weight	Melting Point °C.	Boiling Point °C.
		ACETIC SERIES		
Butyric	C_3H_7COOH	88.10	−4.7	163.5
Caproic	$C_5H_{11}COOH$	116.15	−1.5	202.0
Caprylic	$C_7H_{15}COOH$	114.20	16.0	237.5
Capric	$C_9H_{19}COOH$	172.26	31.5	268–270
Lauric	$C_{11}H_{23}COOH$	200.31	47–48	225
Myristic	$C_{13}H_{27}COOH$	228.36	57–58	250.5
Palmitic	$C_{15}H_{31}COOH$	256.41	63–64	271.5
Stearic	$C_{17}H_{35}COOH$	284.56	69–70	291
Arachidic	$C_{19}H_{39}COOH$	312.51	77	328
Behenic	$C_{21}H_{43}COOH$	340.56	84	306
Lignoceric	$C_{23}H_{47}COOH$	368.61	81–82	—
		OLEIC SERIES		
Hypogaeic	$C_{15}H_{29}COOH$	254.39	33	236
Oleic	$C_{17}H_{33}COOH$	282.45	14	285–286
Erucic	$C_{21}H_{41}COOH$	338.55	33–34	281
		LINOLEIC SERIES		
Linoleic	$C_{17}H_{31}COOH$	280.43	< -18	229–230

The composition of the more common edible fats and oils is shown in Table V.

TABLE V.—*Composition of Edible Fats and Oils*

	Principally Glycerides and Acids of the Following
Butter and substitutes	Oleic, palmitic, myristic, butyric, lauric, caproic and others.
Lard and substitutes	Oleic, palmitic, stearic and linoleic.
Tallow	Palmitic, oleic, and stearic.
Cotton seed oil	Palmitic, oleic, linoleic and stearic.
Olive oil	Palmitic, oleic, linoleic, and arachidic.
Peanut oil	Oleic, palmitic, stearic, arachidic and hypogaeic.
Cocoanut oil	Palmitic, oleic, myristic, lauric, caproic and others.
Corn oil	Palmitic, and oleic.
Palm oil	Palmitic, oleic, myristic, lauric, and others.

Waxes, like fats, are esters but instead of containing the trihydroxy alcohol, glycerine, they contain monophydroxy alcohols of high molecular weight. Besides the esters, waxes may contain free fatty acids, free alcohols, and hydrocarbons. They may be either liquid or solid and of either animal or vegetable origin.

Sperm oil is an example of a liquid animal wax, while spermaceti, wool fat, bees' wax and chinese wax are solid animal waxes.

Solid vegetable waxes are such as carnauba wax, flax wax, and candelilla wax. Waxes, like fats are soluble in ether, benzene, chloroform, carbon tetrachloride, etc.

Mineral oils are the various oils used in lubrication and include gasoline. They are principally hydrocarbons and are quite inert chemically, but are soluble in the ordinary solvents, ether, benzene, chloroform, etc. To the above mentioned oils should be added the mineral oils used in ever-increasing quantities in treatment of constipation.

In connection with the inert character of these mineral oils, we have on two occasions subjected a one-gallon sample of raw primary tank sludge to steam distillation and recovered each time 2 c.c. of a colorless oil which to all intent and purposes was identical with the aforementioned mineral oil.

Animal and vegetable oils and fats are saponifiable, while the mineral oils are not. The sewage plant operator is not much concerned as to the various organic acids and hydrocarbons making up the grease, but rather as to whether they are saponifiable or unsaponifiable, knowing that the unsaponifiable oils are very or wholly resistant to bacterial action, while the saponifiable oils and fats will break down in digestion processes.

It has been stated previously that both calcium and sodium soaps enter the sewage as such at its origin, but "Standard Methods" definition of grease makes no mention of sodium soaps. This seeming discrepency may be accounted for by the fact that the sodium soaps react immediately with the calcium compounds in the water, and that by the time the sewage has reached the treatment plant the sodium soaps have been practically all converted to calcium soaps. We have on several occasions removed pieces of white solid material from the scum in Imhoff tank gas vents, as well as from digester scum, and on analysis have found them to be entirely calcium and magnesium soaps, even though they possessed the original shape of a piece of soap. We have also demonstrated this in the laboratory by immersing a piece of soap in water, and allowing it to stand. The material kept its shape but the sodium was replaced by the calcium and magnesium.

It would appear plausible that no free fatty acids should be present in the sewage itself, although analysis of the grease indicates rather a high percentage. Unless the sewage itself is acid it would seem that any free fatty acids would be neutralized. On the other hand fresh solids collected from a settling tank usually are of an acid reaction.

The presence of free fatty acids might be explained on the assumption of an early and rapid action of the fat-splitting enzyme lipase, acting on the neutral fats.

Buswell and Neave [68] give the analysis of sewage grease as follows:

	Per Cent
Soaps	49.8
Glycerides	33.8
Mineral oils	3.2
Unsaponifiable solids	7.1
Moisture	5.5
Total	99.4

At Los Angeles [69] the composition of grease is given as,

	Per Cent
Free acids including soaps	66
Saponifiable fats	28
Non-saponifiable	6

Knechtges [70] gives the average composition of several greases extracted by petrolic ether and chloroform as

	Per Cent
Free acid	26–78
Soap fatty acid	4–34
Fat fatty acid	2–14
Unsaponifiable	1–31
Soluble only in chloroform	6–19
Ash	11–22

The Removal of Grease from Sewage

Grease may be removed partly as scum, and partly as sludge from the various settling processes. The authorities universally agree that removal of grease at its source is much more effective than removal at the treatment plant.

Fitchburg, Mass.,[71] reports the successful solution of oil and grease troubles by ordinances and cooperation of the persons responsible for their presence in the sewage. The City of Baltimore [72] collects the oils and gasoline wastes from garages to prevent their admission to the sewers. The City of Milwaukee [73] also collects oil and grease from the larger garages.

At Cedar Rapids, Iowa,[74] where large quantities of packing house wastes are treated in the municipal plant, grease is removed by traps in the preliminary treatment of the packing house wastes.

Heilman [75] reports that one thousand grease traps installed at Cologne, Duisburg, Wuppertal and Düsseldorf, Germany, have recovered 33 million pounds of grease, and that 23.1 million pounds of soap have been manufactured from this grease.

Oils have been removed by an electric process, U. S. Pat. 1,746,964, by Bowers, Lathrof and Polatsik.[76] In this process the wastes containing oil are passed through a series of pipes in which copper anodes and cathodes are inserted. By passing an electric current through the apparatus, oil separates out at the anodes.

The earlier methods of grease removal were hand skimming methods, after arresting the floating grease by means of suitable baffles. The skimming is done in some places, in the grit chamber, and in others in the preliminary settling tanks either of the Imhoff type or the plain settling tanks.

Heisig has installed scum baffles in the grit chambers at Milwaukee to help trap the floating oils and greases.[73]

Stanley, at San Antonio, sprinkled sawdust in the flume leading from the screens to the primary settling tanks, to assist in skimming off the floating oils which had been liberated by diffused air applica-

tion.[77] He also used an ingenious method of tracing the origin of the oils, by anchoring wooden floats painted white, in various man-holes in the sewer system.

Cleland[78] at State College, Pa., has also utilized sawdust in skimming of oil and grease in the flowing-through channels of the settling tanks.

The advent of settling tanks equipped with mechanical sludge removal devices led to the development of mechanical skimming devices. Mechanical skimmers are used in the detritus tanks at Dayton, and Akron, Ohio, Allentown, Pa., and other places.

Erie, Pa., is one of the cities employing skimming devices on the primary tanks.[79]

At the Rahway Valley, N. J., plant the grease is skimmed off by mechanical skimmers and then flushed to a grease separation tank where the grease is separated from the water by flotation. The grease is then again skimmed off and buried.[80]

Indianapolis is at present installing grease skimmers on all primary tanks. The skimmings will be pumped to a sludge lagoon for digestion.[81]

Hyde[82] called attention to the fact that mechanical skimmers are not altogether satisfactory, due to winds on uncovered tanks and failure of the oil and grease to rise under plain sedimentation. Nevertheless, the mechanical skimmers remain the most popular of the scum removal equipment, and are used in a great many plants.

It is generally conceded that grease removal tanks in Europe are more efficient than in the United States on account of better design and baffling.[83] Imhoff[84] calls attention to the increased number of grease collecting tanks in Germany, using diffused air and detention periods from five to fifteen minutes.

In 1931 N. T. Veatch called attention to the fact that "the aeration of raw sewage previous to settling seems to be an aid in bringing fats and greases to the surface in the form of scum." Since then, quite a number of installations have been made and it appears to be the most popular method of grease separation at present.

Roe[85] in a paper on pre-aeration of sewage comments as follows: "The primary function of pre-aeration is grease removal. Emulsified particles of oil and grease adhere to the small rising air bubbles and are carried to the surface where a scum is formed. . . . Detention periods vary from ten to thirty minutes, quantity of air 1/20 to 1/10 cu. ft. per gallon. Diffuser areas of ten per cent are adequate." Various methods of air application are used such as diffusion through perforated pipes, porous plates and porous tiles.

Cedar Rapids, Iowa, uses perforated pipes and a system of baffles with nine minutes aeration to separate out grease.

Imhoff uses swinging perforated pipes to supply air to the so-called "tank filter" and gets good de-oiling of the sewage. A plant of this type has been constructed at Kettwig in the Ruhr district for treating wastes from a large woolen mill.[86]

Porous plate diffusers seem to be the most popular of the diffusers used. This type is used at Pasadena, Calif.,[87] using a three minute aeration period; at Lancaster, Pa.,[88] 1.1 to eleven minutes aeration is provided in the influent channel, using 0.03 to 0.06 cu. ft. of air per gallon of sewage. Dodge City, Kans.,[89] using a thirteen minute aeration period removes from forty-four to sixty-three per cent of the grease in the sewage which originally contains 216 p.p.m. grease. Whittier, Calif.,[89] provides for nineteen minutes aeration.

At Hamilton, N. Y.,[90] 0.1 cu. ft. of air per gallon is applied through tubes located in a channel equipped with grease pockets at the sides. Wright, at Salem, Mass., experimenting with different methods of grease removal obtained 57.3 per cent reduction of grease when using an aeration period of seven minutes with 0.18 cu. ft. of air per gallon, which was slightly less than what he obtained by fill and draw sedimentation (57.9 per cent). Continuous flow with skimming baffles (no air) gave 54.4 per cent reduction.

Experiments at San Francisco have demonstrated the value of grease removal, and the plant design incorporated a 15 min. aeration period using 0.05 cu. ft. of air per gallon of sewage. The aeration tank is equipped with baffles.[91]

At Ann Arbor, Mich.,[92] a 12 min. pre-aeration is employed and at Springfield, Ill.,[93] the period is 8 minutes; while at Lansing, Mich.,[94] a 10-min. aeration period is used. It should be noted that this plant is designed to take care of the city's garbage in addition to the sewage. At the Clayton plant, Atlanta, Ga., a pre-aeration period of 15 min. is used.[96]

Washington, D. C.,[95] provides for grease separation in its new plant design, using 3 to 9 min. aeration by diffused air. Denver, Colo., combines pre-aeration for grease removal with preliminary mixing. The air is applied through filtros plates in tanks similar to the Manchester design.[97]

Thackwell [98] at Tyler, Texas, covered his grease removal tanks, and applied a vacuum, thus sucking air into a system of submerged diffuser tubes communicating to the atmosphere.

Another ingenious method of aeration is accomplished by the discharge of screened sewage through high velocity jets placed above the surface of the sewage flowing underneath. In combination with a baffled skimming tank this method removed from 5 to 75 per cent of the grease.[99] This method is included in the design for the Terminal Island plant at Los Angeles. Oklahoma City tried this scheme using tap water instead of sewage but abandoned the process on account of poor results and the high cost of the water.

Methods for the removal of grease by chemicals usually involve the use of acids, although other chemical methods are also in use.

The use of sulfuric acid to remove grease from wool scouring wastes has been practiced for a long time, particularly at Bradford, Halifax and Morley in England.[101] At Halifax the wool scouring and textile wastes are treated by adding sulfuric acid to the raw sewage going to

the precipitating tanks. The sludge is then treated with sulfuric acid to a pH of 3.6. The sludge is then passed through filter presses, the cake is dried and extracted with benzine to recover the grease.[102]

Generally the use of chemicals for this purpose has been patented. In 1907, U. S. Pat. 869,272 was issued to Spence and Ockel for treating sludge with mineral acid and not pressing to recover fat.[103]

The Miles process, U. S. Pat. 1,134,280 (1915) for sewage treatment consists of the addition of sulfuric or preferably sulfurous acid in slight excess, whereby the suspended solids and grease are precipitated. The sludge is then dried and extracted by means of a suitable solvent. The amount of acid used is usually from thirty to forty grains per gallon. The process originated in 1911. In tests of the process at Boston, Mass. 1916), Weston was able to recover from 1800 to 1900 pounds dry sludge per million gallons of sewage, the grease content of which was from twenty-two to twenty-three per cent.

At the New Haven Experiment Station, Mohlman obtained from 368 to 503 pounds of dry sludge per million gallons of sewage. The sludge contained from 23.7 to 32.6 per cent grease.[104]

The Grossman process (U. S. Pat. 1,025,622—1912) calls for treatment of the sludge with sulfuric acid, heating, and distilling.

Chemicals other than sulfurous or sulfuric acid have also been used. At the Hughes Tool Company, Houston, Texas, oil emulsions were broken by adding hydrated lime and agitating with air from perforated pipes. Aluminum sulfate was added, whereupon the oil separates and rises to the surface.[105]

DeVresse[106] has proposed to treat greasy or soapy wastes with a calcium salt such as chloride, sulfate or lactate and lime. The precipitate is then removed by suitable means.

Urbain[107] proposes to remove fats by the reaction of the carboxylic acids (fatty acids) with thionylaniline. (U. S. Pat. 1,935,963.)

Gascoigne[108] has pointed out "when grease in sewage or industrial wastes is high, chlorine may be applied to break this emulsion, allowing thereby liberated grease to float and be collected." One of the earliest users of chlorine for this purpose was deRaeve.[109] By the use of chlorine he was able to obtain much better fat recovery in his treatment of wool-scouring wastes. He stated that the fats are in an emulsified state and protected by a gelatinous, nitrogenous colloid, and that chlorine destroyed this protective colloid.

Faber[110] applied chlorine experimentally at the Woonsocket, R. I., activated sludge plant, since it received a sewage of high grease content. The plant has a grease skimming tank employing six minutes aeration, using porous tube diffusers three feet below the surface. Gaseous chlorine was introduced into the air line just ahead of the diffusers. Chlorine doses of slightly less than 1.5 p.p.m. increased the grease removal ranging from 189 to 442 per cent.

Keefer and Cromwell[111] in semi-plant scale experiments at Baltimore using a similar "aero-chlorination" process and with plain aeration as a control, with chlorine doses from one to ten p.p.m. and aera-

tion periods from five to fifteen minutes, increased the amount of grease separation from 149 to 847 per cent. Generally speaking the maximum amount of grease was obtained using five minutes aeration with five p.p.m. chlorine. The composition of the grease appeared to be little affected, whether separated by air alone or by aero-chlorination, and there was little difference due to time of aeration. Up to doses of five p.p.m. the amount of applied chlorine seemed to be the controlling factor.

Wiest [112] at Lancaster, Pa., tried aero-chlorination in a somewhat different procedure. Instead of introducing gaseous chlorine into the air going to the diffusers, he fed a solution of chlorine in water to the raw sewage directly ahead of the aeration. Using two p.p.m. chlorine with 0.11 cu. ft. air per gallon with 3.4 minutes detention he obtained seventy-six per cent removal of the grease content of the raw sewage. With aeration alone and 0.10 cu. ft. per gallon of air and 3.1 minutes detention (no chlorine) he obtained 53 per cent removal. On the basis of pounds of wet grease removed, aero-chlorination increased the removal 308 per cent.

In a second set of experiments he obtained a grease removal of 78 per cent with aero-chlorination as against 63 per cent by aeration alone.

In further experiments he found that without aeration and without chlorination the primary tanks removed 38 per cent; with aeration alone, 0.14 cu. ft. air per gallon and no chlorine he obtained 50 per cent removal, and with aeration 0.14 cu. ft. per gallon, and chlorine two p.p.m. he secured 80 per cent. With pre-chlorination alone without air he obtained 41 per cent reduction.

Halvorsen [113] by treating packinghouse wastes with chlorine precipitated out a sludge containing 22.7 per cent grease.

In addition to the removal of grease as scum or sludge and the disposal of the grease by various methods, it has been found at the Rothamstead Experiment Station in England that soaps in sewage as high as 250 p.p.m. could be oxidized by filters.[114]

Disposal of Grease

It has been pointed out that grease is removed partly as skimmings and partly as sludge. It is well to bear in mind that by far the greater amount is removed as sludge, and that the ultimate disposal of grease depends on the disposition of the collected scum and sludge.

Skimmings are disposed of by burning, burial, digestion or processing for grease recovery.

Erie, Pa., Wards Island, N. Y., Ann Arbor, Mich., Lancaster, Pa., Pasadena, Calif., and Cedar Rapids, Iowa, are among the plants where the skimmings are burned. At Nürnberg, Germany, the skimmings are mixed with screenings (the skimmings serving as a binding material), briquetted and burned. Aurora, Ill., formerly burned skimmings but has later adopted the practice of adding them to the sludge digestion tanks.

At Rahway Valley, N. J., the skimmings are buried.

At Akron, Ohio, the skimmings go to a sludge dump where they are dried along with the digested sludge.

A word of caution should probably be given with regard to drying of undigested skimmings or putting them into a lagoon. Our experience has been that they are quite odorous.

Most of our present-day plants add the skimmings to the digesters, as they digest and produce large volumes of gas.

Table VI shows the quantity of skimmings removed at several plants, while Table VII shows the composition of several types of skimmings including both the fresh and digested material.

TABLE VI.—*Quantity of Skimmings Removed*

City	Year	Cu. Ft. per M.G.
Aurora, Ill.	1936	0.46
Aurora, Ill.	1937	0.53
Aurora, Ill.	1938	0.36
Galesburg, Ill.	1933	0.79
Galesburg, Ill.	1934	0.74
Galesburg, Ill.	1935	0.48
New Britain, Conn.	1937	2.31
Springfield, Ill.	1933	1.05
Springfield, Ill.	1934	0.80
Springfield, Ill.	1935	0.52
Akron, Ohio	1929	0.24
Akron, Ohio	1930	0.14
Akron Ohio	1931	0.16

TABLE VII.—*Grease Content of Scum*

City	Per Cent Grease Dry Basis	Per Cent of Grease Saponifiable	From
Akron, Ohio	42.00		Grease skimming tank
Pasadena, Calif.	24.50		Grease separating tank
Essen-Rellinghausen, Germany	45 to 60	22	Grease separating tank
Allentown, Pa.	31.00		Imhoff tank scum
Baltimore, Md.	83.60		Imhoff tank scum
Fort Worth, Texas	*17.07	18.99	Imhoff tank scum
Brooklyn, N. Y.	21.07		Imhoff tank scum
Essen-Nord, Ger.	24.10		Imhoff tank scum
Essen-Frohnhausen	18.60		Imhoff tank scum
Essen-Nord West	22.50		Imhoff tank scum
Oberhausen	16.00		Imhoff tank scum
Fort Worth, Texas	47.57	66.72	Primary tank skimmings
Los Angeles, Calif.	33.00		Primary tank skimmings
Salinas, Calif.	30.70		Primary tank skimmings
Waco, Texas	9.77	53.50	Separate digester scum
Fort Worth, Texas	13.66	15.86	Separate digester scum
El Paso, Texas	16.00	8.27	Separate digester scum
Elyria, Ohio	27.20		Separate digester scum
San Antonio, Texas	6.84	23.69	Separate digester scum

* From gas vents.

The Disposal of Grease as Scum or Sludge by Digestion

While the general changes occurring during the digestion of sludge have been known for a long time, it remained for Rudolfs and his associates to provide the stimulus for extensive research into the mechanism of the processes involved. In the early studies the results reported appeared to be contradictory but later the various investigators arrived at the same conclusions. There probably are still some differences of opinion as to the amount of gas produced by grease digestion, and the mechanism of the reactions involved.

Harris and Smith [115] showed the grease content of fresh solids entering an Imhoff tank to be 15.11 per cent, and that of the digested sludge to be 6.83 per cent.

Campbell and Rudolfs [116] found undigested solids to have a grease content of 13.10 per cent and the digested sludge to have 7.08 per cent. O'Shaughnessy had reported that one-third of the grease was lost during digestion, while Bach and Sierp had observed as much as 50 per cent reduction in laboratory experiments on foodstuffs.

From Rudolfs' [117] earlier sludge digestion experiments using fresh solids collected from an Imhoff tank, with no seeding material, and a temperature of 20° C. he concluded that "practically no fatty material was decomposed during the six months incubation."

Bushwell and Neave [118] experimenting on a separate sludge digestion tank also reported that they found no appreciable change in the grease content of the raw and digested sludges (raw 29.2 per cent, digested 30.2 per cent). They however, concluded that in as much as about 30 per cent of the solid material was hydrolized, the grease content must have been decreased correspondingly, otherwise the percentage of grease in the digested sludge would have increased materially.

In further studies [119] they found that in the first or acid stage of digestion, more than 80 per cent of the loss in organic matter could be accounted for as grease digested, and they concluded that grease was rapidly digested in the acid stage with the production of lower fatty acids, and that these acids fermented into methane. The rate of fermentation measured by the amount of gas production indicated that the high grease content of sludge gave a roughly proportional higher rate of gas production. Later [120] they found that sewage grease decomposed in alkaline as well as in acid digestion, and that from 75 to 90 per cent of the digestion occurred in the first three weeks. In further experiments [121] they reported that in acid digestion (pH 7.0–6.1), 150 days at 27° C., 47.3 per cent of the grease was digested.

Rudolfs [122] added various kinds of oils to mixtures of sludge to observe their effect on digestion and found that oils are richer sources of gas than fresh solids, cellulose or casein.

Heukelekian [123] added oils to a synthetic medium and also to a ripe sludge, and found the numbers of bacteria were very much increased, and that mineral oil was far more resistant to bacterial decomposition than animal or vegetable oils. Later [124] he pointed out that the ether soluble portion of fresh solids constituted the largest portion (34.4 per

cent) and that based on reduction of volatile matter, 57 per cent was destroyed by digestion. He also showed [125] that when sewage was aerated, a grease separation took place in which the scum rising to the surface was quite richer in grease than the original fresh solids, and that skimmings yielded more gas per gram of volatile matter destroyed than the fresh solids by about forty per cent, although the rate of digestion seemed somewhat slower.

These findings were confirmed by Keefer and Kratz [126] in their experiments on scum digestion, who found that the higher the fat content, the higher the gas yield.

Bach [127] in laboratory experiments on the digestion of scum found it was easily digested: 36, 77, 30 and 62 per cent, respectively, was digested at Essen Nord, Essen Frohnhausen, Essen Nordwest and Oberhausen.

Haseltine's [128] experiences led him to attribute the high rate of gas production at Salinas, Calif., to the high grease content (340 p.p.m.) of the raw sewage.

Knechtges, Dawson and Nichols [129] experimenting with the digestion of packing house wastes, showed that in a mixture of sludge from domestic and packing house wastes, in 56 days, 50 per cent of the grease was digested; and in 100 day, 65 per cent of the grease in domestic sludge, 72 per cent of the grease in a mixture of equal parts domestic and packing house waste sludge, and 77 per cent of the grease in packing house sludge alone was digested. They state that the lipids (grease) digest to gas more completely than the bulk of other materials constituting the sludge.

Buswell [130] studying two-stage digestion says that 90 per cent of the grease was digested in the first stage.

At Los Angeles [131] experimenting on four-stage digestion it was reported that in 12 days digestion, 88 per cent of the free acids as insoluble soaps, 64 per cent of the saponifiable fats and only 2 per cent of the non-saponifiable greases were digested.

Heukelekian [132] in thermophilic digestion found that at 50° C. in 14 days, 61 per cent of the fats were decomposed as against 66 per cent in 35 days at 22° C.

Ardern's [133] experiments with thermophilic digestion indicated that grease gave twice as much gas in ten days at 50–56° C. as at 25–30° C. He reports 1120 c.c. of gas per gram of grease destroyed in ten days.

The Mechanism of Grease Digestion

Chamberlain [134] demonstrated the presence of the fat splitting enzyme, lipase, in digesting sewage sludge. The quantity of lipase found followed the same trend as the gas production, indicating that the lipase was a factor in stimulating gas production.

The action of the enzyme which is catalytic in nature may be expressed as follows, using glyceryl stearate as an example.

$$C_3H_5(C_{17}H_{35}COO)_3 + 3H_2O + \text{lipase} = C_3H_5(OH)_3 + 3C_{17}H_{35}COOH$$

Buswell and Neave [68] carried out extensive investigations into the chemical changes involved in grease digestion. On account of difficulty in following the chemical steps in the breakdown of the higher fatty acids constituting the fats, they used acids of the same chemical type but lower down in the series. They first attempted to explain the action on the basis of an oxidation reaction but later [135] Buswell and Boruff explain the action on the basis of hydrolysis, according to the following type of reaction.

$$C_nH_{2n}O_2 + \frac{(n-2)}{2} H_2O = \frac{(n+2)}{4} CO_2 + \frac{(3n-2)}{4} CH_4$$

From the formula it will be seen that the products of digestion will exceed in weight that of the original substance.

They found that extracted sewage grease yielded 1050 c.c. of gas per gram, which is 1.13 times the weight of the grease. Pure fats when digested yielded from 1112 to 1433 c.c. per gram, equivalent to 1.33 and 1.54 times the weight of the material added, and for scum itself, 900 to 1000 c.c. per gram. They also showed that glycerol gave a high yield of gas; approximately 88 per cent of the glycerol was recovered as gas. A study of the gas yield indicates that glycerol apparently must decompose as follows:

$$4C_3H_5(OH)_3 = 5CO_2 + 7CH_4 + 2H_2O$$

Rudolfs [136] considers Buswell's yields too high.

Sierp [21] digested various kinds of oils and fats and found that

1 gram olive oil produced	1240 c.c. of gas
1 gram castor oil produced	1112 c.c. of gas
1 gram linseed oil produced	1225 c.c. of gas
1 gram palm oil produced	1245 c.c. of gas
1 gram butter fat produced	1220 c.c. of gas
1 gram lard produced	1210 c.c. of gas
1 gram tallow produced	1285 c.c. of gas

The amount of oil digested in the experiment varied 94.7 per cent to 96.8 per cent of the quantity added.

From these experiments it can be shown that 78 per cent of the oils added were destroyed in 11 days' digestion, 92 per cent in 40 days and 95.5 per cent in 75 days. Such rapid digestion is probably not obtained in plant practice since the greases received are not the pure oils but consist largely of soaps which are much slower to decompose.

At Fort Worth, in laboratory experiments, we have obtained 1268 c.c. of gas per gram of grease digested. In this experiment primary solids were dried and the grease extracted. The extracted solids were then added to seeding material and the gas was collected. In another bottle the same primary sludge, dried but not extracted was treated in the same manner. By this procedure we obtained the amount of gas produced by the digestion of volatile solids non-fat. This was 788 c.c.

per gram. For the fat-containing solids we obtained 994 c.c. per gram of volatile matter. After suitable corrections for the grease remaining in the sludge and scum, we obtained 1268 c.c. gas per gram of grease digested.

The duration of the experiment was 124 days at an average temperature of 26.2° C.

It is noteworthy to observe that in the bottle of material containing the grease-extracted solids, no scum was present at the end of the experiment and that in the other sample a small amount of scum remained which contained 2.85 per cent grease which was only 2.7 per cent saponifiable. In this experiment we obtained 87 per cent reduction of the total grease by digestion, and 99.1 per cent reduction of the saponifiable grease.

In addition to the complete breakdown to gases, of a portion of the saponifiable greases present in sludge, it has been noted that saturated fatty acids tend to become unsaturated during digestion. This was pointed out by O'Shaughnessy in 1914, and also confirmed by Buswell and Neave, since the iodine value of the fats increased from 50–60 per cent up to 100–150 per cent.[68] This has also been reported by Sierp, who shows the characteristics of the saponifiable fats as follows.

	Fresh	Digested
Acid number	201.6	187.8
Saponification number	210.2	230.6
Iodine number	48.8	54.8

Aside from the more or less academic interest in the changes involved in grease digestion, the plant operator is much concerned as to what takes place in his digestion tanks from an operating standpoint. It has been shown that the unsaponifiable or mineral oils yield to decomposition very slowly, therefore the digested sludge should and does show an increase in the proportion of unsaponifiable over the saponifiable material.

For example at Fort Worth the grease in the raw solids is 74.2 per cent saponifiable while in the digested sludge it is only 3.2 per cent saponifiable. At Waco the raw sludge grease was 65.5 per cent saponifiable while the digested sludge grease was 4.4 per cent saponifiable.

During digestion a large portion of the unsaponifiable material is set free, and being lighter than the sludge mixture it tends to float to the surface and produce or rather become incorporated with the floating solids.

This has been confirmed by Rudolfs and Henderson[137] who determined the distribution of grease in a digestion tank and found from 57 to 48 per cent in the scum, and only 20 per cent in the sludge itself.

A portion of the liberated oils also passes off in the digester overflow liquor. A number of analyses at Fort Worth indicate that the solids in the supernatant contain 5.53 per cent grease which is only 15.6 per cent saponifiable.

The incorporation of oil results in compacting of the fibrous mate-

rials in the scum and decreases the permeability of the layer. This scum layer impedes the movement of the scum breaking mechanism of the tank if it is so equipped. Overloading results, and eventually actual stoppage of the mechanism occurs. Stopping the mechanism then allows deeper accumulations of the scum, and later chunks may become broken off, and reach the supernatant overflow lines and cause stoppages.

We have had a number of such stoppages, three of them being rather costly, in that the covers of three of our digesters have been floated upwards, necessitating extensive repairs. We have been informed that this same thing has occurred at Corpus Christi, Texas, and at Colorado Springs, Colorado. We also feel that such a set of conditions was responsible for the rupturing of the diaphragm walls of one of our Imhoff tanks in 1925.[138] Sometime before this accident occurred a considerable quantity of oil reached our plant, to such an extent that a layer one foot deep formed on our tanks. Although the oil was skimmed off, no doubt some of it was carried down into the digestion compartment and later it was released and then rose in the gas vents to become incorporated with fibrous material to form a fairly impervious mat, which entrained the gases from the digesting solids. Although there was no difference in pressure between the flow compartment and the gas vents (the slot being open), the accumulated gas suddenly became released in some manner and resulted in a "water hammer." A number of explanations have been offered but in our opinion this is what we feel actually happened.

Tables VIII and IX show the grease content of sludge before and after digestion.

TABLE VIII.—*Grease in Undigested Sludge*

	Per Cent Grease (Dry Weight)	Per Cent Saponifiable	Remarks
Annandale, N. J.	27.6		
Austin, Minn.	22.7		Halvorsen process.
Baltimore, Md.	25.9		Preliminary settled.
El Paso, Texas	13.54	66.74	Primary sludge.
Flint, Mich.	34.0		
Fort Worth, Texas	19.47	74.19	Primary sludge.
Fostoria, Ohio	12.9		
Indianapolis, Ind.	29.30		Plain aeration sludge.
Indianapolis, Ind.	21.70		Primary sludge.
Indianapolis, Ind.	8.3		Activated sludge.
Jamesburg, N. J.	20.0		
Los Angeles, Cal.	18.20		Primary sludge.
Los Angeles, Cal.	20.30		Activated sludge.
Plainfield, N. J.	14.10		
San Antonio, Texas	20.41	84.33	Primary sludge.
Urbana-Champaign, Ill.	25.2		Avg. 39 samples.
Urbana-Champaign, Ill.	29.2		Avg. 77 samples.
Waco, Texas	11.47	65.61	Primary sludge.

TABLE IX.—*Grease in Digested Sludge*

	Per Cent Grease	Per Cent Saponifiable	Remarks
Akron, Ohio	10.6		
Alpine, Texas	8.67		
Baltimore, Md.	8.9		
Brownsville, Texas	3.48		
Cleveland, Ohio	8.3		
College Station, Texas	16.98		
College Station, Texas	8.08		Septic tank.
Dallas, Texas	15.39		Imhoff tank.
Dayton, Ohio	14.0		
Decatur, Ill.	3.5		
El Paso, Texas	16.20		
Flint, Mich.	10.1		
Flint; Mich.	3.5		Exp. sep. dig.
Fort Worth, Texas	5.38	3.19	Separate digestion.
Fort Worth, Texas	12.46	11.10	Imhoff tank.
Greenville, Texas	5.13		
Greenwich, Conn.	3–5		
High Point, N. C.	6.3		
Indianapolis, Ind.	3.1		
Jacksonville, Texas	14.87		
Laredo, Texas	4.13		
Los Angeles, Cal.	9.1		
Madison, Wis.	10.0		
Marion, Ohio	8.0		
Philadelphia, Pa.	17.7		
Plainfield, N. J.	6.83		
Rochester, N. Y.	12.0		Imhoff tank, average of 7 years.
San Benito, Texas	7.58		
Urbana-Champaign, Ill.	8.6		
Waco, Texas	5.09		Separate digestion.
Waco, Texas	2.97		

POST DIGESTION

It has been observed that after sludge is drawn from a digestion tank and allowed to dry on sludge beds there is a further reduction of the grease. This no doubt is a continuation of the digestion process in the tank.

Tatlock at Dayton, Ohio, shows the following.[139]

Grease Content (Dry Basis)

	Wet Sludge as Drawn	Dried Sludge
1931	12.0	9.0
1932	10.6	9.7
1933	8.7	6.9
1934	10.7	7.9

RECOVERY OF GREASE

While there have been some rather extensive works built to recover grease from garbage, the recovery of grease from sewage has not been

practiced to any great extent in the United States. Although the earlier experiments with the Miles acid process yielded some grease, most plants were concerned with getting rid of the grease with as little handling as possible.

Most of the grease recovery and utilization has been in England and Germany. The status of grease recovery in Germany has been reviewed by Sierp [21] in "Das Fett in der Abwassertechnik," and the following is a short review of the article.

He differentiates the various fats according to their physical condition in the sewage, and their methods of recovery, as follows:

(1) Free fats, which separate out on quiescent settling, on the upper surfaces.
(2) Fats and soaps, in colloids or emulsions, which will remain in suspension.
(3) Heavy oils and tar-like substances heavier than water, which are drawn off at the bottom.
(4) Fat stuffs for the most part, incorporated with sludge particles which precipitate out on settling.

He further classified them as saponifiable, which are the fats of plant and animal origin and coming mostly from food establishments such as slaughter houses, canneries, margarine plants, dairies, wool treating plants, and the unsaponifiable, consisting of mineral greases and oils from garages, workshops, and oil and tar distillation plants, and condenser waters.

It is pointed out that American sludges may contain as high as 45 per cent of their dry weight of grease, while the highest in Germany will be from 18 to 20 per cent. In the poorer communities the grease content will only be from seven to eight per cent and under the present conditions the average for Germany will be about this amount.

Skimmings will contain about 60 to 80 per cent grease. In summer when large quantities of vegetables are eaten the grease content is lower in the sludges than in winter when more fats are eaten.

Figuring that the amount of sludge runs about 50 grams per capita per day (dry basis) and 10 to 20 per cent of grease in the sludge, five to ten grams crude grease which is 90 per cent saponifiable, the sludge should yield from 4.5 to 9.0 grams saponifiable grease per capita per day. The crude grease has the following characteristics.

Acid number	140 to 150
Saponification number	190 to 200
Iodine number	55 to 60

Sierp points out that there are four important factors to consider in any attempts at grease recovery.

(*a*) Which solvent should be used?
(*b*) Shall the grease be extracted from wet or dry sludge?
(*c*) Shall the grease be recovered from the raw or the digested sludge?

(*d*) How does the extraction of the grease from the raw solids affect the digestion of the residue?

Concerning the choice of solvents the work of Knechtges [70] is reviewed. Sierp's data are conflicting, sometimes ethyl ether gives the lowest results, sometimes petrolic ether, with carbon disulfide third, and chloroform the highest results.

In studying the speed of extractions he finds the

Ether extraction practically complete in 6–7 hours.
Petrolic ether and carbon disulphide extraction practically complete in 9 hours.
Chloroform extraction practically complete in 12 hours.

The complete recovery of the solvent is quite important, otherwise the loss of solvent is quite costly.

Concerning the wet or dry extraction the following experiences are given. At Kassel, Germany, the thickened sludge was mixed with sulfuric acid in a tank and then passed to a heater and heated to 100° C. The mixture was then passed through filter presses. The resulting filter cake was broken up, elevated to a drier and dried. The dried material then passed to an extraction tank where the extraction was made with benzol as a solvent. The crude grease was then purified by distillation. The following figures represent the economics of the recovery.

Population of city is 100,000 yielding 15,000 cubic meters of sludge yearly, equivalent to 1600 tons of dry substance. Extraction yields fifteen per cent or 240 tons of grease yearly or 6.6 grams per capita per day. The cost of recovery as 0.69 R.M. ($0.28) per capita per year or 69,000 R.M. ($27,738). The receipt from sales was 84,144 R.M. ($33,826) leaving a profit of 15,000 R.M. ($6088). The cost of construction was 200,000 R.M. ($80,400) which allowed seven and one-half per cent for interest and bond retirement.

Another method for grease recovery is that of H. Grosse-Bohle, who introduced steam into the sludge and obtained a scum containing forty per cent of grease which was skimmed off and re-processed. By this method only a part of the grease, but no soaps were recovered.

At Frankfurt recovery was accomplished with hot filter presses aided by silicic acid and clay, acidified with sulfuric acid. 4.3 kg. were obtained per cubic meter of sludge. Distillation at 315° C. (after acidification with sulfuric acid) with superheated steam was found to be too costly.

Extractions of the wet sludge with benzine were also tried but the experiments never progressed very far, although it is reported that wet extractions have been successful in a number of industrial plants.

Obviously from the foregoing, extractions on the dried material are preferred.

The question of recovery from raw or digested solids is of outstanding importance, as shown by the following table.

	Fresh Sludge	Digested Sludge
Quantity (capita/day)	1 L	0.2 L
Water content	95%	80%
Dry substance (capita/day)	50 grams	40 grams
Grease content	10–15%	3.0–4.5%

The characteristics of the crude greases recovered are as follows:

	Fresh	Digested
Ether soluble grease	88.4%	90.0%
Acid number	143.6	61.8
Saponification number	193.2	130.5
Iodine number	57.3	62.9
Unsaponifiable	14.4	60.2

He concludes that there is no purpose in recovering grease from digested sludge, but that recovery should be made on the raw sludge although there is greater difficulty, since raw sludges contain more colloids and are more difficult to dewater.

Sierp concludes from his studies that mineral oils hinder digestion, and further proposes that a determination of the saponification number of the extracted greases be used as an index of digestion, stating that if the unsaponifiable portion of the recovered grease reaches 50 per cent, then the sludge can be considered as satisfactorily digested.

In conclusion he summarizes:

(1) The only extraction in question is that of the fresh solids.

(2) In existing plants where the value of the digester gas is 5–10 R pfg. (2–4 ¢), the digestion of grease and use of the gas as a power medium is simpler and more valuable than the recovery of grease.

(3) If recovery of the grease is done it should be at the source.

(4) Mineral oils interfere with digestion processes. It is better to keep them out at the source.

(5) Water softening and its relation to grease reduction in the sewage should be studied. He cites examples of American practice.

Recently, attention has been called to a process of grease utilization which is used at Bradford, England.[140] There are four steps which may be used. By the first step the recovered grease is converted to a crude soap in the form of a powder, which can be used as cheap soap, low grade lubricant, flotation of minerals or in metallic soaps. In the second step, the crude soap from the first process is extracted with solvents to remove the unsaponifiable matter. The unsaponifiable matter can then be used as a constituent of lubricating oil, or as a protective coating on metals. The purified soap is utilized as a cheap soap. In the third step the purified soap is decomposed with acids, and pure hard saponifiable, stearine-like fatty acids are obtained. The fourth step consists of the distillation of the fatty acids to produce first-class fatty acids and stearines. The soaps from these fatty acids are used as bases in metal polish, the stearines in candles or lubricating greases.

In conclusion it may be said that the purpose of this article was to stimulate a little thought on the subject.

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THE PRODUCTION OF CARBON DIOXIDE IN THE BIOLOGICAL FILTER BED

By H. Wilson and J. A. McLachlan

Biochemical Laboratory, City of Johannesburg, South Africa

In a previous study [1] on carbon dioxide production in the activated sludge process, the authors concluded from a carbon balance on a laboratory scale that only about 10 per cent of the transformation products of carbon appeared as carbon dioxide in the effluent air. A parallel study of the operation of the filter bed was then projected because of the essentially close similarity between the two processes. The present communication records the results of a carbon balance study on the filter bed process.

For the purpose of this study, the filter bed process is fundamentally different from the activated sludge process in that a variable fraction of the carbon input is retained indefinitely in the filter. It is therefore impossible to complete the balance, and the same confirmation of the equality of carbon input and carbon output is lacking. For this reason, particular care has been taken to insure complete adsorption of CO_2 in the effluent air.

It is realized that in general the carbon output in the effluent can bear little relation to the carbon input, owing to the unknown retention of coagulated compounds, and of compounds adsorbed or assimilated by living organisms, and to the discharge of humus of unknown history. The value of the study is concentrated therefore in the extent of carbon dioxide production under various operating conditions.

Experimental

Two glass tubing filters were set up side by side, each 1⅜ inch in diameter and 5 feet long, with graded pumice stone approximately ⅜ inch as media. The filters were fed with settled sewage filtered through coarse French Grey filter paper from the same reservoir, the effluent collected through a U-trap and the air space in the effluent receivers connected to the effluent air tube, to insure that any CO_2 discharged from the effluent was absorbed.

The necessity for enclosing the system completely made forced ventilation necessary, and to that extent precludes the application of the results directly to practical operating conditions. Two filters were used to enable comparisons to be made in a reasonable time and on the same sewage.

Considerable difficulty was experienced in securing a uniform continuous dose to each filter with the small flows required. It was considered desirable to feed each filter from the same reservoir, but not necessarily at the same rate. The method described by Jenkins,[2] for a constant drip by means of an air controlled siphon was found satis-

factory, with modification of the air-inlet capillary for the smaller doses of a 1⅜ in. diameter filter: 0.2 mm. capillary tubing was drawn out to a long fine capillary, and this was further constricted by touching the capillary tip with a small flame until the desired rate was obtained. The siphon delivery tube was divided by a Y-piece for feeding each filter; constriction of one of these was necessary when equal flows were required. The filtered sewage reservoir was elevated about 2 ft. 6 ins. above the top of the filter columns.

CO_2-free air was passed in at the bottom of each filter through an air meter, and the CO_2 in the effluent air absorbed in two Meyer tubes

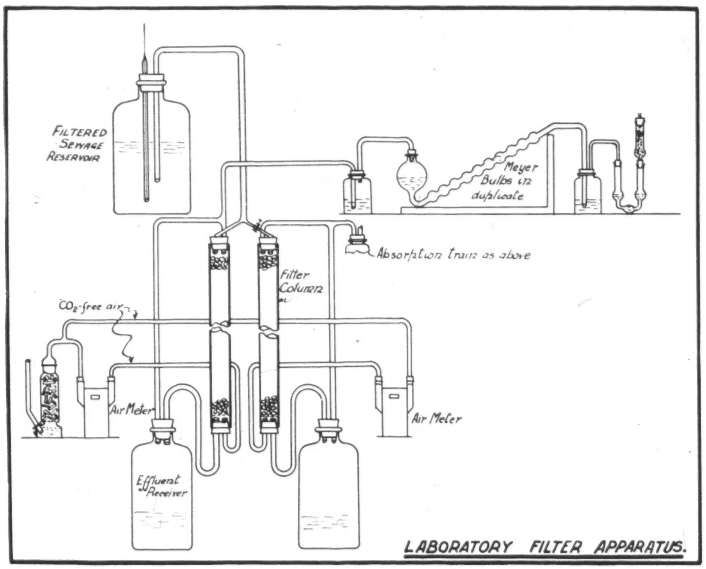

Fig. 1.

in series using a saturated solution of barium hydroxide, preceded and followed by a wide bottle to hold about 100 c.c. of the barium solution in shallow depth to keep the resistance head as low as possible. A U-tube holding a few mls. of barium solution served as a guard-tube with a final guard-tube of Ascarite preventing access of atmospheric CO_2. In all the runs recorded well-nitrified (10 to 39 parts per million nitrate nitrogen) clear effluents were obtaind.

Determination of Carbon by Wet Combustion

The method used in the last study as described by Mills,[3] was again employed.

Results

To avoid confusion in studying the analytical data, the basis on which the figures are calculated is given here in detail.

Sewage is regarded as containing carbon compounds in two types of combination, viz., (1) organic carbon compounds of varied complexity, and (2) carbon dioxide as the free gas in solution, and in a limited number of forms of combination as carbonates and bicarbonates. This approach is consistent with the analytical methods used, and convenient for that reason. The strong acid solution used in the analytical determination, followed by air blowing, releases all the carbon dioxide which is inorganically combined as carbonates and bicarbonates of the common bases, and a relatively small amount of the gas in loose organic combination. It is generally agreed that in the absence of strong oxidizing agents such as chromic acid, permanganates etc., insufficient oxidation of organically combined carbon takes place under the conditions of the determination.

The addition of chromic acid thereafter and short boiling and air blowing, results in complete conversion of carbon in all forms of organic combination to gaseous carbon dioxide.

In Table I the results obtained on aliquots taken for analysis have been calculated from the measured volumes used in the experiment

Table I.—*Input and Output of Inorganic and Organic Carbon*

Filter	Run	Input		Output					Duration of Run, Hours
		Filtered Sewage		Effluent Including Humus			Effluent Air		
		As Inorganic Carbon, Grams	As Organic Carbon, Grams	As Inorganic Carbon, Grams	As Organic Carbon, Grams	Volume Collected, Mls.	As Inorganic Carbon, Grams	Air Used, Cubic Feet	
A.	1.	0.099	0.363	0.061	0.118	800	0.222	0.48	$6\frac{2}{3}$
B.	2.	0.112	0.409	0.052	0.085	900	0.179	0.24	$6\frac{2}{3}$
A.	3.	0.143	0.620	0.121	0.158	1320	0.170	0.24	$5\frac{1}{2}$
B.	4.	0.099	0.432	0.048	0.088	920	0.144	0.08	$5\frac{1}{2}$
A.	5.	0.248	0.717	0.114	0.248	1630	0.204	0.46	6
B.	6.	0.232	0.673	0.067	0.187	1530	0.077	0.60	6
A.	7.	0.029	0.391	0.082	0.142	1040	0.166	0.66	$4\frac{1}{2}$
B.	8.	0.034	0.451	0.101	0.149	1200	0.157	0.60	$4\frac{1}{2}$
A.	9.	0.185	0.525	0.143	0.305	1620	0.115	0.62	$4\frac{1}{2}$
B.	10.	0.173	0.492	0.146	0.185	1520	0.117	0.84	$4\frac{1}{2}$

In these tables, Total Carbon = Inorganic carbon present as free CO_2, carbonates and bicarbonates + organic carbon oxidized by chromium trioxide in sulfuric acid.

to the total input and total output of carbon in the two forms described above. In all cases, the figures for carbon are expressed as the element carbon.

In Table II, the results in Table I have been re-calculated to a percentage basis by assuming the total carbon added as settled filtered sewage feed equal to 100.

Table III is a re-calculation of the same data based on the input of organic carbon only in the settled filtered sewage feed as equal to 100.

TABLE II.—*Carbon Balance, Filter Beds*

Results on a Percentage Basis
Total Carbon Input = 100

Run	Output			
	As Inorganic Carbon in Effluent	As Organic Carbon in Effluent	As Carbon Dioxide in Effluent	Unaccounted for
1.	13.2	25.6	48.2	13.0
2.	10.0	16.3	34.4	39.3
3.	15.9	20.7	22.3	41.1
4.	9.1	16.6	27.2	47.1
5.	11.8	25.7	21.2	31.3
6.	7.4	20.7	8.5	63.4
7.	19.5	33.8	39.6	7.1
8.	20.8	30.7	32.4	16.1
9.	20.2	43.0	16.2	20.6
10.	22.0	27.8	17.6	32.6

TABLE III

Organic Carbon Input = 100

Run	Output	
	As Organic Carbon in Effluent	As CO_2 in Effluent Air
1.	32.5	61.2
2.	20.8	43.8
3.	25.5	27.4
4.	20.4	33.4
5.	34.6	28.4
6.	27.8	11.5
7.	36.3	42.4
8.	33.0	34.8
9.	58.0	22.0
10.	37.6	23.8

DISCUSSION OF RESULTS

Several experimental studies have been devoted in recent years to the extent of the production of carbon dioxide from aerobic treatment of settled sewage in the activated sludge process.[4] A recent study by Jenkins and Roberts,[5] on the rate of flocculation of organic matter by activated sludge and the rate of oxidation of the dispersed and floccu-

lated organic matter, leads the authors to the conclusion that about 20 per cent of that portion of the organic carbon which is quickly flocculated is oxidized to carbon dioxide, while solid matter removed during later stages of aeration is more fully oxidized.

As far as the authors have been able to find out, no laboratory study has been made to determine the extent of production of carbon dioxide in the biological filter bed. The present study has been undertaken as part of a general investigation of the significance of carbon dioxide in aerobic sewage treatment processes.

The general conclusion from the results obtained is that carbonaceous matter is oxidized to carbon dioxide to a much greater extent in filter beds than in the activated sludge process. It is not considered legitimate on the present experiments to separate from the total carbon dioxide in the effluent air, that due solely to the combustion of organic carbonaceous matter. In contrast to the production in an activated sludge process, of approximately 10 per cent of total carbon input as CO_2 in the effluent air, this study shows a production of 8.5 per cent to 48.2 per cent of the carbon input as CO_2 in the effluent air of a filter bed. The results from Run 1 show a higher conversion to CO_2 than the remainder, probably owing to the fact that the smallest throughput was obtained in this run, while maintaining an average flow of air. Based on the input of organic carbon only, the figures are modified to 11.5 to 61.2 per cent of the input of organic carbon.

The work described was done in the Biochemical Laboratory, Public Health Department, City of Johannesburg.

The authors wish to express their thanks to the Public Health Committee, to the Medical Officer of Health (Dr. A. J. Milne), and to the City Engineer (Dr. E. J. Hamlin) for the facilities and permission to carry out this work.

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THE USE OF COPPERAS–SODIUM SILICATE AS A SEWAGE COAGULANT

By E. Hurwitz and F. M. Williamson

Prin. Sanitary Chemist, and Assistant Civil Engineer, The Sanitary District of Chicago

Investigation of the use of chemicals as additional treatment for sewage at the West Side Works of the Sanitary District of Chicago, led to the discovery that a combination of copperas and sodium silicate gave strikingly efficient results at comparatively low cost.

Silicates were first applied as an aid to coagulation of impure water by Martin Nahnsen (1) who recorded his discovery in a patent issued in Germany in 1884 and in this country in 1889. The idea then lay dormant until it was rediscovered by Baylis (2) in 1937. Both these investigators used silicates in conjunction with alum in the treatment of water supplies.

Laboratory Tests

Mr. Baylis' experiments and some tests made at Waukegan, Ill., by Swope (3) suggested the possibility that some such combination of chemicals might be effective in treatment of West Side Sewage. Laboratory experiments were conducted in which sodium silicate-alum and sodium silicate-copperas as well as a variety of other chemicals were tested. The results of a few typical tests are shown in Table I.

These results indicated that significantly better removals of B.O.D. could be obtained with copperas and sodium silicate on the weak West Side sewage than with other chemicals tried. In tests Numbers 5 and 6 this combination was compared directly with both ferric chloride and alum-sodium silicate. The per cent removals of B.O.D. by copperas-sodium silicate in these tests were 72.2 and 73.5, respectively. Alum sodium silicate removed 69.1 and 65.5 per cent; ferric chloride, 65.0 and 67.8. Results such as these coupled with the low cost of treatment indicated by these laboratory tests led to the institution of large scale experiments at the West Side experimental plant.

Description of Experimental Plant

Sewage for the testing plant was pumped into an open flume in the chemical house where it was divided into two streams. One portion was left untreated as a control and carried directly to the Imhoff tank and magnetite filters. The other portion was treated with the chemicals under observation and passed in order through a flash mixer, a flocculator, an Imhoff tank, and a magnetite filter. Flash mixing was provided by diffused air. The detention period in this tank was approximately five minutes. Flocculation was accomplished in two tanks equipped with paddles mounted on horizontal shafts. The detention period in the flocculation tanks was thirty minutes. The settling tanks were re-constructed from one of the existing Imhoff tanks, which was

TABLE I.—*Chemical Precipitation—Laboratory Tests*

Test No.	Chemicals. Pounds per million gallons						Analysis, p.p.m.			Reduction B.O.D.	
	Ferric Chloride	Chlorinated Copperas	Copperas	Alum	Lime	Sodium Silicate	Turbidity	pH	B.O.D.	P.P.M.	Per Cent
1	0	0	0	0	0	0	67	7.4	69		
	200						55	6.9	22	47	68.1
		300					47	7.1	30	39	56.5
		200			150		53	8.5	25	44	63.8
2	0	0	0	0	0	0	83	7.3	122		
				300			50	7.0	42	80	65.6
				300		270	47	7.0	42	80	65.6
		300				270	50	7.0	42	80	65.6
3	0	0	0	0	0	0	77	7.3	80		
			200			180	53	7.1	20	60	75.0
				200		180	—	7.1	19	61	75.3
4	0	0	0	0	0	0	74	7.3	147		
	200						52	7.0	44	103	70.0
	200					180	47	7.0	40	107	72.8
				300			63	6.9	43	104	70.8
				300		180	57	6.9	38	109	74.2
5	0	0	0	0	0	0	59	7.3	97		
	200						40	6.9	34	63	65.0
			300				80	7.2	39	58	59.8
			300			100	20	7.2	27	70	72.2
				300		100	35	7.1	30	67	69.1
6	0	0	0	0	0	0	75	—	87		
	200						54	—	28	59	67.8
				300		100	54	—	30	57	65.5
			300			100	56	—	23	64	73.5
7	0	0	0	0	0	0	92	7.3	76		
	200						69	7.1	21	55	72.4
			200				103	7.2	30	46	60.6
			200			100	66	7.3	19	57	75.0
			200			150	64	7.2	16	60	79.0

split to give two identical tanks, one for plain settling, the other for settling of chemically treated sewage. They provided a settling period of one hour at 2.83 M.G.D. At 1.89 M.G.D., which was the quantity treated in most of these tests, the detention period was 1.5 hours. The magnetite filters were of the downward flow type.

The chemical dosing equipment consisted of two 3000 gallon solution tanks, solution pumps, orifice boxes, two dry chemical feeders and chlorinating equipment. Figure 1 shows the general plan and Figs. 2, 3, and 4 show some of the equipment used in the plant. A detailed de-

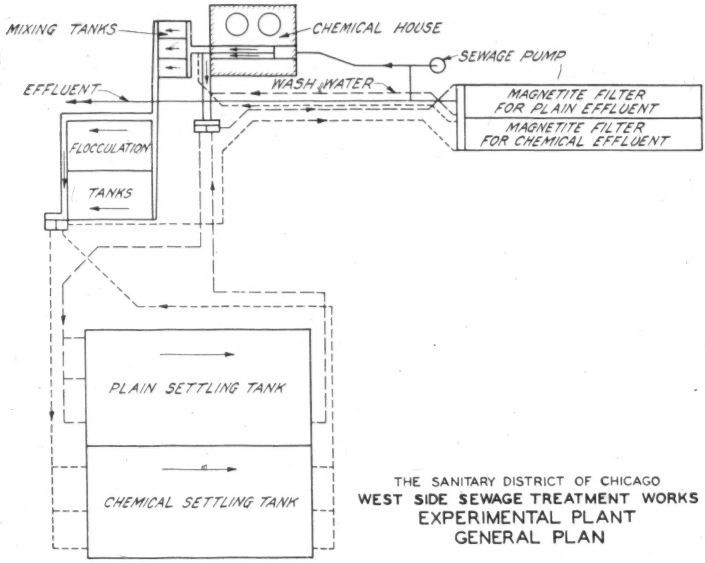

FIG. 1.

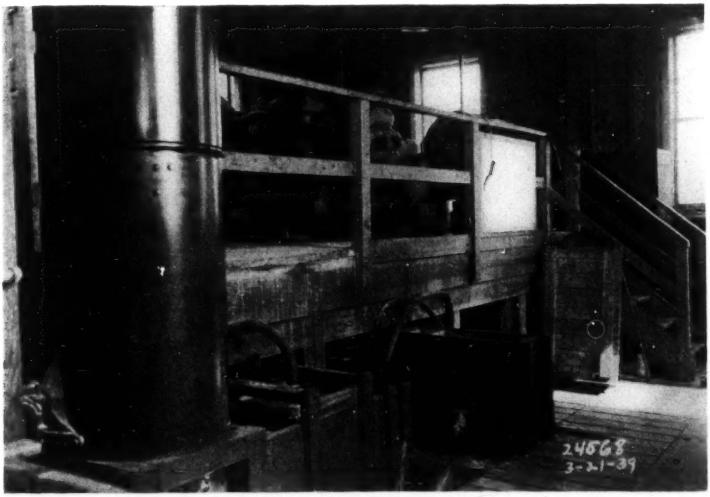

FIG. 2.—Copperas feeder and weir boxes.

FIG. 3.—Flash mixer and floeculator.

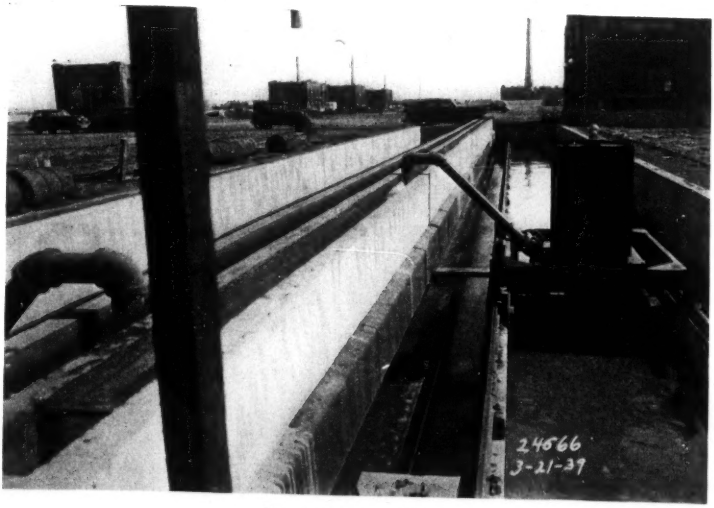

FIG. 4.—Magnetite filter.

scription of the plant and appurtenances was given in an article by T. L. Herrick (4).

The Preparation of Sodium Silicate Solution

The sodium silicate solution was "activated" according to the method of Baylis. Batches amounting to 2820 gallons were prepared at a time. For this purpose 470 pounds of 42° Bé sodium silicate (Na_2O: 3.25 SiO_2) which contained 29–30 per cent SiO_2, was diluted with 1075 gallons of water. The resulting solution contained 5 per cent by weight of 42° Bé sodium silicate or 1.5 per cent SiO_2. Using phenolphthalein as the indicator the quantity of sulfuric acid (66° Bé) necessary to reduce the alkalinity of this solution to 1000–1200 p.p.m. ($CaCO_3$) was determined. This amounted to 12.8 per cent of the weight of the 42° Bé sodium silicate used. Then with constant stirring in order to avoid localized "jelling" the proper weight of sulfuric acid (60 pounds) was added slowly. This solution was allowed to age in quiescent state for from one to two hours with frequent checking by observing a sample dipped from the large batch for first signs of "cloud" or opalescence. At this point the batch was diluted to the full 2820 gallons. The solution now contained 2 per cent by weight of 42° Bé sodium silicate or 0.6 per cent SiO_2. Thus "activated" the sodium silicate was ready for use. The 2820 gallon batch was sufficient for a three day run. Experience showed that the silicate lost much of its activity if held much longer.

Discussion of Results

The results of these tests are shown in Table II. Copperas, $FeSO_4 . 7H_2O$, was dosed at rates ranging from 96 to 232 pounds per million gallons. The "activated" sodium silicate solution was fed at rates which provided quantities of 42° Bé sodium silicate, Na_2O: 3.25 SiO_2, varying from 109 to 122 pounds per million gallons.

Reduction of suspended matter obtained by treatment with copperas and sodium silicate by settling only, varied from 61.6 to 76.4 per cent, with an average reduction of 70.8 per cent. This represent an increase of 12.3 per cent over plain settling. The reductions in B.O.D. by copperas-sodium silicate after settling ranged from 57.1 to 77.6 per cent. The average was 68.5 per cent, which represents an increase of 19.6 per cent over plain sedimentation. Filtration of the effluent through magnetite filters increased the reduction of suspended solids to 83.5 per cent and of B.O.D. to 78.8 per cent. Increases in the amount of copperas and silica used produced only a slight increase in the reduction of suspended solids and B.O.D.

It is apparent from results in Table II that somewhat better reductions were obtained by the use of the designated quantities of copperas and sodium silicate than were obtained by the other chemicals used, in the quantities shown. Ferric chloride, which gave the best results after the copperas-sodium silicate combination, showed an average reduction

TABLE II

CHEMICAL PRECIPITATION EXPERIMENTS

SUMMARY OF OPERATING DATA

	OPERATING PERIOD	OPERATING DATA: CHEMICAL DOSING – LBS. PER M.G.								CHEMICAL ANALYSES: pH			SUSPENDED SOLIDS: Parts per Million			SUSPENDED SOLIDS: Per Cent Reduction			5 DAY B.O.D.: Parts per Million			5 DAY B.O.D.: Per Cent Reduction			REMARKS
		Copperas as $FeSO_4 \cdot 7H_2O$	Sodium Silicate, 42° Baumé	Sulphuric Acid, 66° Baumé	Chlorine as Cl_2	Ferric Chloride as Dry $FeCl_3$	Lime as CaO	Pickle Liquor as $FeSO_4 \cdot 7H_2O$	Settling Period Hours	Raw Sewage	Flocculated	Chemical Effluent Settled	Raw Sewage	Plain Settled Effluent	Chemical Effluent Settled	Plain Sedimentation	Increase by Chemicals	Total by Chemicals	Raw Sewage	Plain Settled Effluent	Chemical Effluent Settled	Plain Sedimentation	Increase by Chemicals	Total by Chemicals	
1	1938 June 20-30	232	114	14.6	–	–	–	–	1.46	7.3	7.1	7.0	171	70	51	59.1	11.2	70.3	98	51	22	48.0	29.6	77.6	
2	Nov. 12-14, 22-26 Dec. 1-4, 11-23	191	109	13.9	–	–	–	–	1.50	7.7	7.4	7.1	146	78	56	46.5	15.1	61.6	119	71	51	40.3	16.8	57.1	
3	July 1-6	176	121	15.5	–	–	–	–	1.47	7.3	7.0	6.9	131	48	31	63.5	12.9	76.4	67	32	18	52.2	21.0	73.2	
4	Sept. 15-30	142	108	13.8	–	–	–	–	1.50	7.3	7.2	7.1	116	52	37	55.1	13.0	68.1	78	45	28	42.3	21.8	64.1	Copperas and Sodium Silicate
5	July 7-17	132	122	15.6	–	–	–	–	1.50	7.4	7.1	6.9	142	52	35	63.3	12.0	75.3	85	35	20	58.8	17.7	76.5	
6	July 18-25	109	123	15.7	–	–	–	–	1.50	7.3	7.1	6.9	145	54	36	62.8	12.4	75.2	76	40	28	47.4	15.8	63.2	
7	July 26-Aug. 7, Sept. 8-14	96	109	13.9	–	–	–	–	1.45	7.3	7.1	6.9	129	52	40	59.6	9.4	69.0	78	36	25	53.8	14.1	67.9	
8	1939 Jan 6-19	329	–	–	41	–	–	–	1.50	7.7	7.3	7.0	140	96	84	31.4	8.6	40.0	112	84	63	25.0	18.8	43.8	
9	1938 Apr 21, 26-30 May 1-18, June 4-19	301	–	–	47	–	–	–	1.50	7.4	7.0	7.0	130	62	52	52.4	7.6	60.0	100	58	30	42.0	28.0	70.0	Chlorinated Copperas
10	1939 Jan. 20-26 Apr. 4-9	256	–	–	37	–	–	–	1.42	7.6	7.2	7.0	136	95	63	30.1	23.5	53.6	127	87	63	31.5	18.9	50.4	
11	Feb. 1-17	182	–	–	29	–	–	–	1.50	7.7	7.3	7.1	127	99	58	22.1	32.2	55.3	107	84	59	21.5	23.4	44.9	
12	1938 Mar. 12-Apr. 17	–	–	–	–	203	–	–	1.48	7.4	7.0	6.9	134	72	38	46.4	25.4	71.8	102	65	38	36.2	26.5	62.7	
13	Oct. 10-23	–	–	–	–	168	–	–	1.50	7.5	7.2	7.0	141	58	38	58.9	14.1	73.0	86	53	30	38.4	26.7	65.1	Ferric Chloride
14	Oct. 1-9	–	–	–	–	114	–	–	1.50	7.5	7.2	7.0	117	61	41	47.9	17.1	65.0	83	51	31	38.5	24.1	62.6	
15	1937 Sept. 7-Oct. 31	–	–	–	–	141	197	–	0.97	7.4	8.5	7.5	118	78	37	33.9	34.6	68.5	91	60	32	34.0	30.9	64.9	
16	1937 Dec. 4-31 1938 Jan. 1-16, 21-31	–	–	–	–	158	202	–	1.50	7.6	8.4	7.8	120	79	41	34.2	31.7	65.9	109	82	46	24.7	33.1	57.8	Ferric Chloride and Lime
17	1938 Feb. 1-16	–	–	–	–	128	315	–	1.50	7.8	8.8	8.5	161	101	45	37.2	34.8	72.0	115	79	44	31.3	30.4	61.7	
18	1938 Oct. 26-29 Nov. 2-5	–	120	15.3	–	–	–	218	1.50	7.5	7.1	6.9	129	72	64	44.2	6.2	50.4	93	57	45	38.7	12.9	51.6	
19	Nov. 9-11, 15-21	–	112	14.3	–	–	48	175	1.50	7.6	7.3	7.0	127	70	59	44.9	8.6	53.5	107	64	50	40.2	13.1	53.3	Pickle Liquor and Sodium Silicate
20	Dec. 6-10	–	115	14.7	–	–	57	222	1.50	7.7	7.4	7.2	163	72	46	55.9	15.9	71.8	136	77	55	43.4	16.1	59.5	

Note: Per Cent Reduction is based on raw sewage.

in suspended matter after settling of 69.9 per cent as compared with 70.8 per cent for copperas-sodium silicate. In B.O.D. the average reduction by ferric chloride was 63.5 per cent as compared with 68.5 per cent for copperas-sodium silicate.

Theories of the Mechanism of the Reaction

The combination of copperas and sodium silicate forms a tough, readily settleable floc which apparently has greater adsorptive power than the other chemicals used if the greater reduction of B.O.D. can be considered a measure of this power. The role of sodium silicate in formation of this floc was studied by Baylis and by Christensen and Lavine (5). It is Baylis' belief that the silicon which gives aid to coagulation is in the form of a colloidal hydrous silicon dioxide having a strong negative charge. This colloidal precipitate forms the framework on which the hydroxides of aluminum or iron adhere. Christensen and Lavine made extensive laboratory studies and also surveyed the available literature for an explanation of the mechanism responsible for the effectiveness of silicates as an aid to coagulation. In general they agree with the theory advanced by Baylis. They point out, however, that in the case of aluminum salts, and very probably in the case of iron salts, the colloidal hydroxide particles are positively charged. The mechanism of the aid to coagulation consists in the action between the positively charged hydroxide particles and negatively charged silica. Ionic attraction causes an agglomoration of particles which results in a large, easily settleable floc.

It is also worthy of note, that in the experiments in which copperas and sodium silicate were used for sewage purification, aeration by mechanical means was not essential to the formation of the floc. In some hundreds of tests on samples collected immediately after the application of copperas and sodium silicate and at other points in the process, ferrous iron was never found to be present. Long time records show that under summer conditions dissolved oxygen is never present in the influent to the West Side plant. The fact that ferrous iron was not found suggests the possibility that the silica may have catalyzed the reaction between the ferrous iron and oxygen absorbed from the surface of the different units. The very dilute character of the sewage would favor maintenance of oxidized iron.

Cost of Treatment

Mention was made that this combination of chemicals offered a comparatively inexpensive method of treatment. At the time these tests were made copperas was quoted at approximately $14.00 per ton plus shipping and handling, say $16.00 per ton; sodium silicate was quoted at $13.00 per ton plus freight and handling, say $14.00 per ton; 66° Bé sulfuric acid was priced at approximately $16.00 per ton delivered. At these prices the cost of chemicals for treatment with copperas and sodium silicate during these tests ranged between $2.76 and $1.64 per

million gallons sewage. The cost for treatment with ferric chloride ranged between $4.10 and $2.28 per million gallons sewage. Since the time when these experiments were conducted, the price of ferric chloride has been as low as $30.00 per ton, and at this price it compares favorably with the cost of the copperas-sodium silicate combination. The relative fluctuations in price would therefore influence the choice of chemicals. Copperas is recovered from spent steel pickling liquors, a waste product of iron and steel processing, disposal of which is a serious problem yet to be solved by the industry. The efficiency of copperas when used with sodium silicate, as shown by these tests may lead to its increased use, if these results are confirmed elsewhere and on stronger sewage. Larger use would result in lower cost. Likewise a large steady demand would tend to lower the cost of sodium silicate. We may reasonably expect therefore that the cost of chemicals for treatment with copperas-sodium silicate would, under these circumstances, be appreciably lower than the estimate shown.

Use of Steel Pickling Liquor

Table II shows some results obtained by use of spent pickling liquor from steel pickling tanks, and sodium silicate. The work done with this material was still in the exploratory stage when the experiments were discontinued but they were sufficient to demonstrate that the pickling liquor could be used in place of copperas. The pickling liquor was delivered to the experimental plant in batches containing iron in concentrations ranging from 12.0 to 27.6 per cent computed as ferrous sulfate, $FeSO_4.7H_2O$. Free sulfuric acid ranged from 1.55 to 4.49 per cent. These wastes were diluted at the plant and fed to the sewage in solutions containing 4.5 to 10.3 per cent $FeSO_4.7H_2O$ and 0.57 to 2.5 per cent H_2SO_4. It was found necessary to neutralize part of the free acid. In these tests this neutralization was done with lime after the pickling liquor had been dosed into the sewage. However it might have been more effectively accomplished by treatment of the pickling liquor directly with scrap iron thus increasing the content of copperas.

The reductions of B.O.D. and suspended solids obtained warrant consideration of the use of pickling liquor for this purpose wherever this material is conveniently obtainable.

Acknowledgment is made of the help and suggestions of Mr. L. C. Whittemore, Engineer of Treatment Plant Design and Dr. F. W. Mohlman, Director of Laboratories, in the operation of the experimental plant. The plant was built under the direction of Mr. William H. Trinkaus, Chief Engineer of the Sanitary District of Chicago. Operation was under Mr. L. M. Johnson, Engineer of Maintenance and Operation and Mr. A. H. Goodman, Engineer of Plant Operation, West Side Sewage Treatment Works. The Public Works Administration was represented by Mr. Joshua Desposito as Resident Engineer.

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Stream Pollution

THE REGULATION OF STREAM POLLUTION IN THE RARITAN RIVER BASIN BY THE NEW JERSEY STATE DEPARTMENT OF HEALTH *

By Leroy Forman and R. P. Johns

Sanitary Engineer-Chemist, and Assistant Chemist, New Jersey State Department of Health

With the exception of the Delaware River, the Raritan River is the largest stream in New Jersey. It is formed by the junction of the North and South Branches, with their tributaries, at a point about three miles west of the town of Raritan. From the junction of these two streams, the main body of the Raritan River flows in a southeasterly direction to Raritan Bay.

The Raritan River is tidal and navigable for small boats to a point about four miles above the City of New Brunswick. The head of tide water is Fieldville Dam.

The total drainage area of the Raritan River watershed is 1100 square miles. The watershed has a total population of 325,641 (1937). The lower valley of the Raritan River has a large urban population within its drainage area while the other portions of the river have mostly rural population. The per cent increase in population growth for the entire watershed between 1900–1910 was 20.9; between 1910–1920, 29.4; between 1920–1930, 29.1; and between 1930–1937, 7.9. The 1937 populations were estimated according to the U. S. Bureau of Census formula.

The yearly average flow of the Raritan River at Fieldville Dam (head of tidal water) is 1254 c.f.s. or 810 m.g.d., and the summer average flow is 751 c.f.s. or 486 m.g.d. The modern low flow record on September 12, 1932 was 80.9 c.f.s. or 52.3 m.g.d. In these cases the average summer flow is about 60 per cent of the average yearly flow and the extreme low flow is close to 6.5 per cent of the yearly average.

The Raritan River and its tributaries had become the depository for wastes, industrial and sanitary. By diluting processes, the river can absorb certain quantities of wastes, but the settlement of many industries in the Raritan Valley and the growth of its municipalities eventually produced too large and varied a load for the river to assimilate. While the volume of domestic sewage and industrial wastes discharged into the river untreated has greatly increased, the volume of flow now remains practically unchanged. Above the confluence of the Millstone River, a tributary, the streams are used or may be used for public potable supplies and special laws apply. Seven million gallons a day are diverted into another watershed and a water company

* Presented at the Twelfth Annual Meeting of the New York State Sewage Works Association, New York City, January 19, 1940.

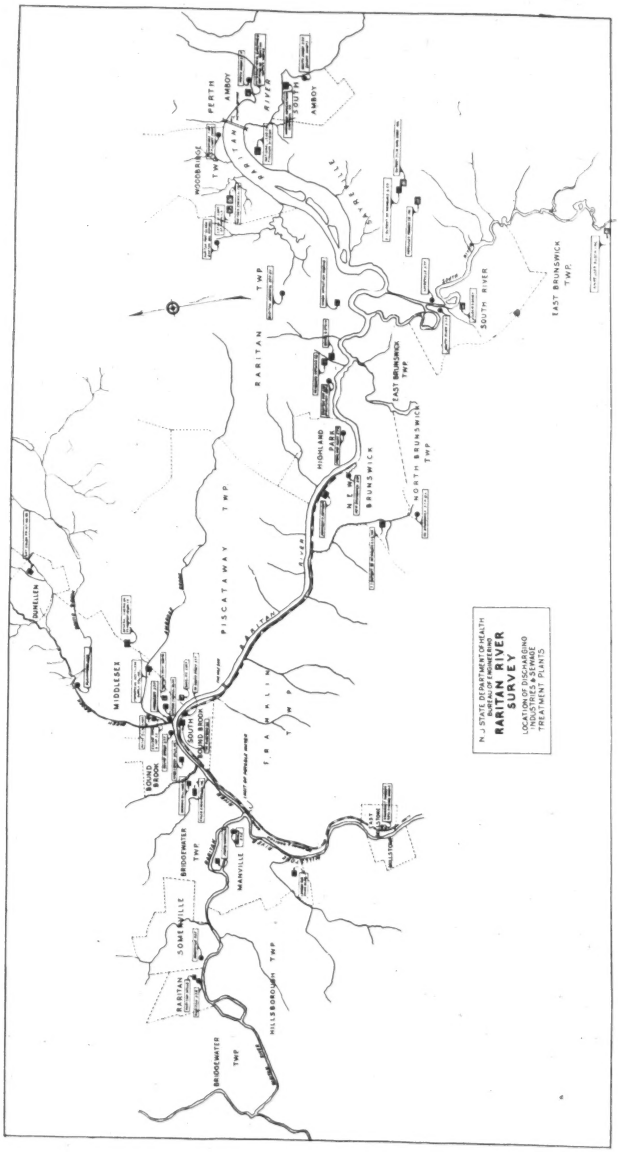

N.J. STATE DEPARTMENT OF HEALTH
BUREAU OF ENGINEERING
RARITAN RIVER
SURVEY
LOCATION OF DISCHARGING
INDUSTRIES & SEWAGE
TREATMENT PLANTS
PERTH AMBOY
SOUTH AMBOY
WOODBRIDGE TWP
RARITAN RIVER
SAYREVILLE
RARITAN TWP
SOUTH RIVER
EAST BRUNSWICK TWP
EAST BRUNSWICK TWP
HIGHLAND PARK
NEW BRUNSWICK
NORTH BRUNSWICK TWP
PISCATAWAY TWP
DUNELLEN
MIDDLESEX
BOUND BROOK
SOUTH BOUND BROOK
FRANKLIN TWP
BRIDGEWATER TWP
MANVILLE
HILLSBOROUGH TWP
SOMERVILLE
RARITAN
BRIDGEWATER TWP

FIG. 1.

has the authority, we believe, to divert up to twenty million gallons a day. Because of the varied uses of the river water, the problem became quite complicated. The condition of the river was becoming progressively worse and constituted a grave menace to the health, welfare, property, and recreational facilities of the people residing along the stream.

The problem presented is not one of absolute prevention of artificial pollution but one of elimination of gross and objectionable pollution, control of the quality of the receiving waters, and improvement of conditions in one of the great rivers of New Jersey where a dense population is supported by an ever increasing industrial development. The

FIG. 2.—Raritan River—5 mile dam. Head of tide water. Between the Borough of Bound Brook and City of New Brunswick.

measures that have been taken are in accord with the provisions of the statutes relating to stream pollution and the policies of the Department of Health of the State of New Jersey, which have been established in accordance with the authority vested in the Department by such statutes. Abatement of industrial pollution is not quickly and easily attained, however, as the treatment of many industrial wastes is in the pioneering stage. There are also many legal, scientific and economic problems, all of which are inter-related.

SEWAGE

In 1929, a firm of engineers, acting under authorization given by the Legislature to the Port Raritan District Commission, made an in-

vestigation of the pollution of the Raritan River, and based upon its findings, made certain recommendations for the abatement of the pollution. The recommendations were placed before civic organizations and municipal officials of the various cities and boroughs located along the Raritan River in the hope of developing and initiating by cooperative means some plan of procedure for abating the pollution produced by the discharge of raw sewage from the several municipalities. It soon became apparent that any progress by cooperation was hopeless. The Legislature, therefore, in 1931 included in its appropriation bill, Chapter 382 of the Laws of 1931, an item to the State Department

FIG. 3.—Raritan River looking up-stream toward City of New Brunswick. Confluence of Delaware and Raritan Canal at left. (Tidal.)

of Health entitled "To enforce the laws with respect to the Pollution of the Raritan River—$25,000."

Based upon the findings of the State Department of Health in its survey of the pollution of the Raritan River, notices were issued to the various municipalities commanding them to cease the pollution and to dispose of their sewage in a manner satisfactory to the Department. In all, there were seventeen notices served, four under the Potable Water Act and thirteen under the State Sewerage Act. Because of the depression, most of the municipalities, already in financial difficulties, petitioned for an extension of time within which to comply with the terms of the notices. On February 2, 1932, the Department of Health granted a two year extension of time, subject to the condition

that each municipality benefiting by this grant must admit the allegations set forth by the Department and, further, must agree to enter into a consent decree in the Court of Chancery. At the expiration of the two year period, the financial conditions of the municipalities had not improved and the terms of the notice were not complied with.

In 1933, the Public Works Administration was created, one of the underlying principles being to assist in the financing of useful public works and sewage treatment projects for municipalities apparently ranked high in priority. However, only one municipality along the Raritan River proceeded on its own initiative to apply for and sub-

FIG. 4.—Dam and 6 feet weir constructed to measure volume of dye wastes discharging to Raritan River. Gauge in background.

sequently to receive funds for the construction of a sewage treatment plant. The failure of the other municipalities to apply for funds caused the Department of Health to request the Attorney General to institute court proceedings and on April 2, 1935, decrees were issued by the Chancery Court commanding the municipalities to cease the pollution of the waters of Raritan River and to dispose of their sewage in a manner satisfactory to the Department of Health of the State of New Jersey.

All of the municipalities except two made prompt application to the Public Works Administration for loans and/or grants to finance the construction of sewage treatment plants and all of the said applications received favorable consideration. Contempt proceedings were

instituted against the two municipalities who did not apply for funds with the result that eventually applications were made and recently granted. In addition to the new treatment works, several municipalities in the Raritan Valley having sewage works were under notice to enlarge or improve their sewage treatment works. These municipalities also applied for loans and/or grants for the construction of additions and alterations, all of which were approved.

FIG. 5.—Acid wastes discharging into South River, a tributary of the Raritan River.

All plants, with the exception of the two where contempt proceedings against the municipalities were instituted, and in which sewage treatment works are now under construction, have been completed and placed in operation during the years 1937, 1938 and 1939.

It therefore appears that the Raritan Valley sewage treatment program was not a joint undertaking but rather each municipality has constructed its own plant. The treatment plant for the Borough of Raritan consists of chemical coagulation, sedimentation, mechanical straining

and chlorination. Vacuum filtration, sludge drying and incineration with the Borough garbage takes care of the sludge. For Somerville, the method of treatment consists of chemical coagulation, sedimentation with mechanical strainers, chlorination and vacuum filtration of sludge, with subsequent disposal on farm land. Both of these projects included the construction of the necessary intercepting sewers and pumping stations.

The Borough of Manville, which is situated at the junction of the Millstone River and Raritan River, constructed a sewer system, pumping station and treatment plant. The treatment plant consists of sedimentation, a sprinkling filter of the rotary distributing type, secondary settling, chlorination, separate sludge digestion and glass-covered sludge drying beds.

Intercepting sewers and a sewage treatment plant were constructed at the Borough of Bound Brook. The plant has chemical coagulation, sedimentation, chlorination (pre and post), chlorine detention, two-stage separate sludge digestion and glass-covered sludge drying beds. Gases from sludge digestion are collected and used for heating purposes.

Middlesex Borough constructed a complete system of sanitary sewers and a treatment plant providing for chemical coagulation, sedimentation, chlorination (pre and post), chlorine detention, separate sludge digestion and glass-covered sludge drying beds. Means are provided for burning the gas produced in sludge digestion for heating purposes.

Up the Green Brook Valley at the Plainfield Joint Treatment Works, additions, alterations and improvements have been completed. These additions and alterations consist of a comminutor, increased primary sedimentation units, a circular settling tank with magnetite strainer for secondary clarification following the sprinkling filters; pumps, lines, etc. for the return of certain portions of the final effluent to the primary tank effluent to permit continuous operation of the sprinkling filters; and additional sludge digestion capacity. At Metuchen, which is located on one of the tributaries draining into Bound Brook and thence into the Raritan River, the old sewage treatment works were practically rebuilt. The old circular Imhoff tank was converted into a sludge digestion tank; new rectangular sedimentation tanks with continuous sludge removal, new sprinkling filters with rotary distributors followed by final sedimentation and chlorination were constructed.

Returning to the main Raritan River, the City of New Brunswick has constructed a system of intercepting sewers, pumping stations and sewage treatment works. Chemical precipitation and chlorination, separate sludge digestion and vacuum filtration of the digested sludge are provided. Gas produced in the digestion of sludge is collected and used for heating purposes. Across the river at Highland Park, the sewage treatment works provide for sedimentation with continuous sludge removal, chlorination, separate sludge digestion and glass-covered sludge drying beds. This project also included the necessary intercepting sewers and pumping station.

Up the South River, a major tributary of the Raritan River, the

Borough of Sayreville and the Borough of South River constructed identical plants. Each plant provides for chemical coagulation, clarifiers with mechanical strainers, vacuum filtration of undigested sludge and chlorination. The necessary intercepting sewers and pumping stations were provided.

The new sewage treatment works at Perth Amboy was the first to be started and completed on the Raritan River. Extensive systems of interceptors and pumping stations for domestic sewage and industrial wastes and a treatment works consisting of chemical coagulation, clarifiers with mechanical strainers, chlorination and vacuum filters for undigested sludge were provided.

As the second step in the improvement of the sanitary conditions of the Raritan River and its tributaries, the Department of Health of the State of New Jersey, in the fall of 1936, authorized an investigation for the abatement of pollution by industries discharging industrial and sanitary wastes into the waters direct.

The survey had for its objectives the following: (1) The determination of the quantity and characteristics of the wastes dicharged by the industries located in the Raritan Valley; (2) The effect of the wastes upon the receiving waters; (3) What treatment, if any, the wastes should receive before being discharged to eliminate or materially reduce the pollution load of the receiving waters; and, (4) The investigation of the efficiency of operation and treatment of the new sewage treatment plants constructed along the Raritan Valley.

The program for the abatement of industrial pollution is similar to that used with the municipalities; improvement was sought by cooperation, if possible, and through action in the Court of Chancery, if necessary.

General Considerations

This investigation covers a stretch of the Raritan River of 25 miles measured in a straight line or 32 miles as measured along the center of the river, from above the Town of Raritan to the Raritan Bay at a point where the Arthur Kill flows into the Bay or just below Perth Amboy on one side and South Amboy on the opposite side. The Raritan River is an intrastate stream, and therefore, this survey is an entirely independent problem solely under the jurisdiction of the New Jersey State Department of Health. In this stretch the sewage from all or part of twenty municipalities and two privately owned sewers is emptied into the river. At the beginning of this investigation a very large part of the sewage was still receiving no treatment as the new sewage treatment plants were not completed, although at a few places the old settling tanks to remove the coarser floating particles, installed many years ago, were in service. Three comparatively recent and modern sewage treatment plants were in operation at Perth Amboy, the Clara Barton Section of Raritan Township, and Raritan Arsenal.

In addition to sewage from municipalities emptied into the river, 37 industries were found discharging their industrial wastes and/or sani-

tary wastes directly into the river. Many more industries were connected to the sewer systems of the municipalities in which they are located. Some industries which have no trade wastes discharge their sanitary wastes to the river and others have cesspools or septic tanks.

Granting the necessity of utilizing the Raritan River as a natural drainage system for "used water" in the form of treated sewage and treated industrial waste, it becomes the duty of the State Department of Health to regulate the degree or intensity of treatment of each type of waste to an extent that the waters are restored to reasonable purity. In this condition the health, welfare, comfort and property of the inhabitants are protected and enhanced. Other reasons for the necessity of restoring the waters of Raritan River to a state of reasonable purity are: to maintain the purity of that section of the river that is or may be used as a source of public potable water supply; maintenance of fish and other aquatic life; recreation (boating, bathing and fishing); protection of shellfish culture in certain areas of Raritan Bay; navigation; economic and industrial uses; aesthetic reasons; and to insure the quality of the waters at the boundary of the area under the jurisdiction of the Interstate Sanitation Commission, Victory Bridge, at least equal to or better than the requirements of the said Commission.

Causes contributing to the pollution of the Raritan River may be summarized as follows:

(*a*) The discharge into the river of large quantities of industrial waste and raw sewage.
(*b*) Insufficient fresh water for dilution with the present pollution load.
(*c*) The oscillation of highly polluted water by the tide.

As a result of this investigation and the taking of appropriate action where necessary, it is believed the waters of the Raritan River can be improved, at least, to the following extent:

(1) The maintenance of at least 50 per cent of oxygen saturation at all times.
(2) The elimination of all free acid or caustic alkali and poisonous chemicals.
(3) The waters will not be substantially discolored or the turbidity materially increased or oil and grease appear on the surface, or the waters be otherwise objectionable to the sight.
(4) The *B. coli* density will be comparable to that of a normal stream flowing through a similar terrain.
(5) The waters will be free of objectionable odors.

As the sewage treatment plants were completed and operated for several months, detailed inspections of one or two weeks duration were made upon each. Considerable difficulty was encountered at the plants using chemical treatment. It was usually found that an insufficient quantity of chemicals was used, whether an iron salt and lime, or alum was used as the coagulant. This was especially true during the times of the day when the sewage was strongest. By cooperating with the

proper municipal representatives or plant operators, an established method of operation was determined by numerous hourly tests upon the raw sewage, over 24-hour periods. After due time, detailed inspections of the plants were repeated.

Probably the greatest difficulty in obtaining continuous satisfactory operation of the new sewage treatment plants was at those plants having sand strainer units in connection with the clarifiers. More than a year of extensive experimenting by the contractor was necessary at the plants before a reasonably satisfactory sand washing mechanism was developed that would permit continuous operation of more than a few weeks duration without the sand or screen, or both, becoming clogged. Prechlorination once or twice weekly during the low flow periods of the night is recommended as a precautionary measure for preventing bacterial growths and slime formation from clogging the slots in the screens upon which the sand is placed. Each of these plants has had detailed inspections made upon it at least twice since it was first placed in operation. Detailed reports upon the inspections of each plant have been written and will be made a supplement of the main report.

The situation as regards sewage at the beginning of the present survey, July 1937, was:

Eleven municipalities and one private sewer were discharging raw sewage amounting to 14.73 m.g.d., from a population of approximately 147,080, having an oxygen demand equivalent of 30,339 pounds.

Five municipalities were discharging insufficiently, inadequately or improperly treated sewage amounting to 6.467 m.g.d., from a population of approximately 74,310, having an oxygen demand equivalent of 4,198 pounds.

One municipality and one United States agency had sewage treatment plants installed, treating 0.231 m.g.d., from a population of approximately 1,975, and the effluents had an oxygen demand equivalent to 300 pounds.

The status of the construction of sewage treatment plants as of October 1, 1939, and the amount of sewage, population and biochemical oxygen demand in parts per million and pounds per day discharged into the Raritan River or its tributaries by municipalities were as follows: (It should be obvious that the latter figures were not obtained on October 1, 1939, but at the time of inspections).

One municipality was discharging raw sewage amounting to 0.87 m.g.d. from a population of approximately 8,700, having an oxygen demand equivalent to 3,909 pounds. A sewage treatment plant for this municipality is under construction and was about 85 per cent complete as of October 1, 1939.

Three municipalities were discharging insufficiently, inadequately or improperly treated sewage amounting to 1.367 m.g.d. from a population of approximately 11,310, having an oxygen equivalent of 2,184 lbs. per day. One of these municipalities has an entirely new plant under construction and was about 10 per cent complete as of October 1, 1939. Improvements and additions are being made at another municipality in this group.

Thirteen municipalities had new or improved sewage treatment plants constructed as of October 1, 1939 (eleven new plants, one absorbing a private sewer, and two improved plants). The quantity of treated sewage from these plants amounts to 20.447 m.g.d. from a population of approximately 205,165, having an oxygen demand equivalent to 13,540 pounds.

Summarizing, eleven new sewage treatment plants constructed, and the additions and alterations to two existing plants, reduced the biochemical oxygen demand discharged to the Raritan River or its tributary from a total of 27,669 lb. per day to 12,941 lb., equal to a removal of 14,728 lb. or 53.2 per cent. The suspended solids discharged prior to the construction of the eleven new plants and the additions and alterations to the two existing plants were 23,273 lb. per day and after construction 6,707 lb., equal to a removal of 16,566 lb. or 71.1 per cent. *B. coli*, partially completed test, were reduced from an average per plant of 205,000 per c.c. to 100 per c.c. More efficient chlorination in the future at certain plants will greatly reduce this latter figure.

The raw sewage from two municipalities where new sewage treatment plants are under construction is still being discharged into the Raritan River. This raw sewage is equivalent to 5,818 lb. of biochemical oxygen demand and 3,903 lb. of suspended solids per day. If it is assumed the same percentage reductions will be obtained in these two constituents as the average reductions obtained at the new plants constructed (53.2 of the biochemical oxygen demand and 71.1 per cent of the suspended solids), then the biochemical oxygen demand should be reduced to 2,723 lb. per day and the suspended solids to 1,128 lb. per day.

The four existing plants discharge an effluent containing an equivalent of 578 lb. of biochemical oxygen demand a day and 353 lb. of suspended solids a day.

All of the above calculations are based upon results obtained from 24 hour composite samples collected at the time or times of investigation. Hourly quantities for the composite samples were varied according to the rate of flow.

Two policies have recently been adopted by the Department of Health of the State of New Jersey, one relating to new establishments locating in the Raritan Valley and the other to the degree of treatment of wastes required by existing industries.

(1) Be it Resolved, By the Department of Health of the State of New Jersey, at a meeting held on the fifteenth day of November, A. D. one thousand nine hundred and thirty-eight, that under the power and authority granted to the said Department of Health by the provisions of Chapter 10, Title 58 of the Revised Statutes, said Chapter being entitled "Pollution of Waters," Chapter 11, Title 58 of the Revised Statutes, said Chapter being entitled "Water and Sewerage Plants and Systems in General," Chapter 12, Title 58 of the Revised Statutes, as amended by Chapter 224 of the Laws of 1938, said Chapter being entitled "Sewerage Districts and Sewerage District Boards," and particularly by said Section R. S. 58: 12–3 above-quoted, that all sewage and other polluting matter, the source of which was not created, established, caused or maintained prior to the fifteenth day of November, A.D. one thousand nine hundred and thirty-eight, or which was not discharged into the Raritan River prior thereto, shall, before discharge into the waters of the Raritan River, be subjected, as a minimum, to a method of treatment equivalent to that obtained by sedimentation, oxidation (or nitrification) and chlorination, so that a well clarified and highly oxidized effluent, low in bacterial content, will be discharged from the said new sources of pollution; and,

Be it Further Resolved, That this policy, hereby established shall apply to the discharge of sewage, industrial and/or manufacturing wastes and other polluting matter and shall apply to any person, firm or corporation, municipal or otherwise; and,

BE IT FURTHER RESOLVED, That this policy shall become effective immediately.

(2) "BE IT RESOLVED, By the Department of Health of the State of New Jersey, at a meeting held on the thirteenth day of June, A.D. one thousand nine hundred and thirty-nine, that under the power and authority granted to the said Department of Health by the provisions of certain sections of Title 58 of the Revised Statutes, domestic sewage, industrial wastes or other polluting matter now discharged into, or now permitted to flow or fall into, or now placed in the waters of the Raritan River and its tributaries from the mouth of the said river to the confluence of the Raritan and Millstone Rivers shall be subjected to a method of treatment, as a minimum, which will produce an effluent which will, at least, meet the following requirements:

1. The effluent shall contain no free acidity; that is, all titratable acidity shall be neutralized.
2. The effluent shall be free of noticeable floating solids, scum, oil, grease or sleek.
3. The effluent shall be sufficiently free of color or turbidity, or both, so that after dispersion in the receiving waters, or not more than one thousand (1,000) feet above or below the point of effluent discharge, it will not substantially discolor, alter the natural color or add to the turbidity of the receiving waters.
4. The effluent shall be free of caustic alkalinity or other toxic or deleterious substances.
5. The effluent shall be free of offensive odors.
6. The effluent shall be of such quality that the most probable number of organisms of the *Coli-Aerogenes* Group shall not exceed one (1) per cubic centimeter in more than twenty-five per centum (25%) of the samples of effluent tested by the partially confirmed test; and, provided, further, that no single sample shall contain more than ten (10) organisms of the *Coli-Aerogenes* Group in one (1) cubic centimeter.
7. The effluent after dispersion in the receiving waters, or not more than one thousand (1,000) feet above or below the point of effluent discharge, shall not reduce the dissolved oxygen content in such receiving waters below fifty per centum (50%) saturation. The aforesaid dissolved oxygen content shall be determined by the average of the results of the analysis of at least six (6) samples collected at approximately equal intervals during any eight hour (8 hr.) period of any day; and,

BE IT FURTHER RESOLVED, That this policy, hereby established, shall apply to the discharge of sewage or other polluting matter; and,

BE IT FURTHER RESOLVED, That this policy shall become effective immediately; and,

BE IT FURTHER RESOLVED, That this policy shall not repeal the policy established by the Department of Health of the State of New Jersey at a meeting held on November 15, 1938; said policy relating to stream pollution, the source of which was not created, established, caused or maintained prior to November 15, 1938; and,

BE IT FURTHER RESOLVED, By the Department of Health of the State of New Jersey that a copy of this resolution be made a part of the records of the Department of Health of the State of New Jersey, to be used in all prosecutions made under the provisions of certain sections of Title 58 of the Revised Statutes, for the control or abatement of existing pollutions in the waters of the Raritan River and its tributaries from the mouth of the said river to the confluence of the Raritan and Millstone Rivers.

INDUSTRIES AND INDUSTRIAL WASTES

The Raritan Valley is an important industrial center for both the large and small industries. The exceptionally favorable geographical position of the lower Raritan Valley accounts very largely for its industrial activity. The products manufactured are quite variable and include a large variety of chemicals, organic and inorganic, tile and brick, dyes and intermediates, pharmaceuticals, house shingles and other asbestos fiber products, plastics, textiles, medical and surgical supplies, and etc.

In this survey, 193 industries were investigated and 37 were found discharging wastes directly into the Raritan River or its tributaries. Many others discharge wastes into municipal sewer systems. The Department of Health of the State of New Jersey is not particularly interested in the latter group because under the statutes lodged for enforcement in the said Department, failure of a municipal sewage treatment plant to produce desired or expected results because of the presence of industrial wastes therein makes the municipality responsible, and whatever action may be taken is against the municipality and not against a contributor to its sewer system and sewage treatment plant.

Detailed investigations have been made at the 37 industries found discharging wastes into the Raritan River or its tributaries. During the investigations, information was obtained as to products manufactured, raw materials, processes, sources of water supply, number of employees, operating hours, disposition of sanitary wastes, volume of wastes, and whatever other pertinent information was considered necessary pertaining to the particular industry. Composite samples of the wastes were collected, varying in length of time from six hours to twenty-four hours, depending upon the hours of employment per day or the length of time required to complete cycles of operation or processes.

Fact finding reports were written upon the investigation of each industry in which the results of analysis of the samples were included, a discussion of the results was included, pointing out the objectionable features, and recommendations were made. The reports containing the recommendations were forwarded to the interested industry with the request that the State Department of Health be advised as to why the recommendations should not be complied with after due deliberation. The State Department of Health cooperated with the industry in every manner possible, granting extensions of time for more study upon proper application, when it was believed the industry was earnestly making progress. The Department of Health is gratified by the co-operative attitude and willingness shown by the great majority of the industries in improving the condition of the Raritan River.

It is recognized that many industrial wastes are very difficult and expensive to treat. No uniform or standard procedures are applicable to industrial wastes as there are in the treatment of sanitary sewage.

In all, it was found that the 37 industries were discharging an average of 38 million gallons per day of wastes, untreated, into the Raritan River or its tributaries. The volume of wastes from the individual industries varied from a few hundred gallons a day to fifteen million gallons a day. In spite of limitations, it is believed proper and helpful in a study of river conditions produced by both industrial wastes and sewage to convert industrial wastes to their equivalents in population based upon biochemical oxygen demand. On this basis it was found that the sum of the oxygen requirements of the industrial wastes discharged into the Raritan River and its tributaries at the time of inspections was 74,679 pounds a day. On the basis of 0.17 pounds of oxygen require-

ment per day per capita for sanitary sewage, the population equivalent of the industrial wastes was over 439,000. This is near the population of such cities as Newark, New Jersey, Kansas City, Missouri or Cincinnati, Ohio. It is about 140 per cent of the combined population of the municipalities bordering the section of the Raritan River included in this survey.

Other pertinent data of the survey indicated that: (*a*) 146,066 pounds of mineral acids were discharged daily; (*b*) the more common toxic materials discharged included heavy metals, especially arsenic, copper and lead, phenol, formaldehyde, benzaldehyde and other complex organic derivatives; and (*c*) bacterial pollution by industrial wastes was negligible.

The status of waste treatment at the 37 industries after two years of study and cooperation, as of January 1, 1940, is: 19 industries either have treatment plants installed or have removed their discharges entirely from the river, 4 industries were not considered polluting at the time of inspection; 7 industries have treatment plants under construction; 4 industries are still studying proposed methods of treatment; 2 industries are under legal notice; and 1 is constructing a new larger plant off the watershed.

During the summer of 1940, at which time it is believed the project will have been practically completed, a study will be made and samples collected of the waters of Raritan River for comparison with the results obtained at the beginning of the survey. The writers have heard scores of times during the past summer and fall from residents of the Raritan Valley of fish (weaks and blues) being caught for the first time in 20 years in the lower Raritan River.

The Raritan River Surveys represent an expenditure of approximately $50,000 and consumed 3,900 man-days. The Department of Health was exceptionally fortunate in having assigned to it as Special Deputy Attorney General for the Raritan River projects, Mr. Russell B. Watson of New Brunswick, whose interest, judgment and knowledge of the problems presented and counsel were frequently sought and graciously given.

In the summer of 1937 the pollution of that part of the Raritan River included in this survey was general. The greatest pollution occurred for a distance of three miles adjacent to and below the City of New Brunswick. The dissolved oxygen content was uniformly zero on ebb tide and averaged about 20 per cent of saturation on flood tide. Another heavily polluted section was a three mile stretch above and below the Borough of Bound Brook in which stretch there were discharged industrial wastes from seven plants and sewage from three municipalities.

The entire tidal section of South River, an important tributary to the lower Raritan River, was grossly polluted, the dissolved oxygen content was generally zero and always less than one part per million on both the ebb and flood tides.

RESULTS OBTAINED TO DATE

Sewage: 21.5 million gallons per day:

Biochemical Oxygen Demand, Reduced	53.2%	From:	27,669 lbs.
		To:	12,941 lbs.
Suspended Solids Reduced	71.1%	From:	23,273 lbs.
		To:	6,707 lbs.
B. Coli (Partially Completed Test), Reduced	99.9%	From:	205,000 per plant
		To:	100 per plant

Industrial Wastes: 38 million gallons per day.

It is anticipated from the results obtained by treatment or elimination of industrial wastes at 19 of the 37 industries that the percentage reduction of the objectionable features will be greatly in excess of that secured by the treatment of sewage.

It is believed there are five factors which enter into and are essential for the successful carrying out of any project of this kind, namely: (1) sufficient moneys; (2) adequate laws; (3) capable legal representatives; (4) 100 per cent cooperation by superiors; and (5) the good-will and cooperation of industries and municipalities.

BUFFALO RIVER STREAM POLLUTION STUDIES, 1936–1939

By G. E. Symons and Wm. L. Torrey

Chief Chemist and Asst. Sanitary Chemist, Buffalo Sewer Authority

Prior to July 1, 1938, approximately 15 per cent of the domestic sewage and 30 per cent of the industrial wastes of Buffalo were discharged into a small stream which flows through the city. Pollution of this stream, which is known as the Buffalo River, has been a problem to the City of Buffalo since the growth of the municipality began to follow industrial development. The importance of this problem in recent years has been second only to that of a need for sewage treatment to prevent pollution of the Niagara River.

There were several factors which affected the condition of this stream and the action of polluting wastes. The stream had a drainage area of only 436 square miles (1). Most of the fall was in the upper end of the tributaries. The stream discharged into Lake Erie at the entrance to Buffalo Harbor and had been dredged to form a part of the harbor. This dredged basin, which extended for a distance of 5.6 miles from the mouth, was greatly affected by the rise and fall in the level of Lake Erie. During the summer months, when there was very little flow in the river, this basin became a huge septic tank.

In April, 1936, the Bird Island Laboratory of the Buffalo Sewer Authority, in conjunction with Greeley and Hansen, Engineers, began a series of studies on the Buffalo River and its pollution. These investigations were continued by the Laboratory after the inauguration of sewage treatment. It is the purpose of this report to summarize the work of 45 months from April, 1936, to December, 1939, inclusive, and to develop a perspective of the complexity of the pollution problem and the effect of removing domestic sewage and some industrial wastes from the stream on and after July 1, 1938.

Technique of the Investigation

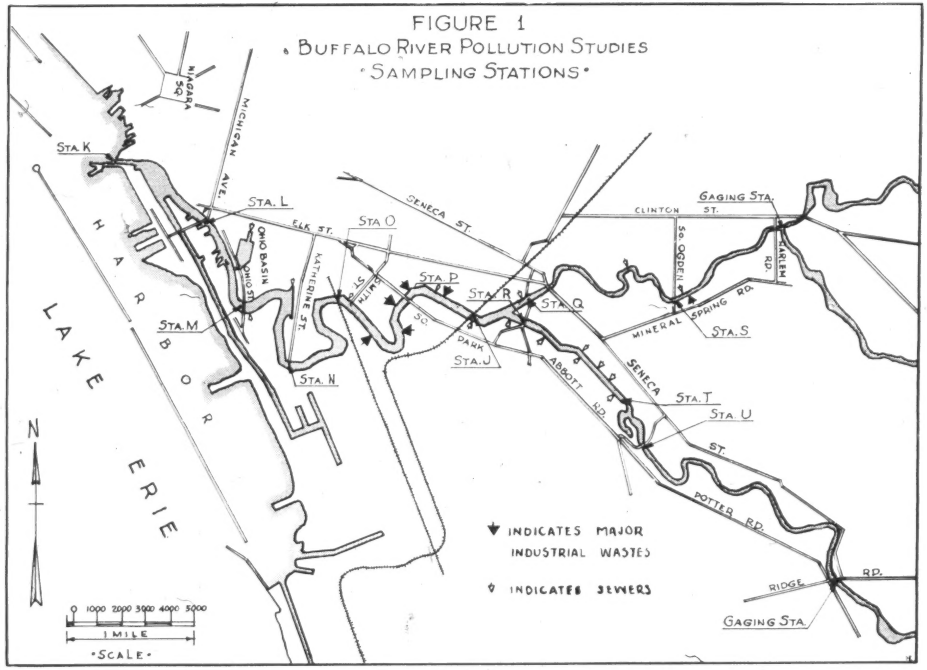
Figure 1 is the map of the Buffalo River and its tributaries. In this report, the name Buffalo River has been applied to the stream below the junction of Buffalo Creek and Cazenovia Creek. The map shows the location of the sampling and gaging stations. Gaging stations were established on the tributary Buffalo and Cazenovia Creeks outside of the city. Table I lists all of the stations, and the distance from each to the mouth of the river.

Regular monthly sampling at these stations was begun in June, 1936, although several dissolved oxygen surveys had been made in April and May of that year. The surveys were made by truck except the first five which were made by boat. Samples were collected in a large depth sampler which obtained individual samples for dissolved oxygen, oxy-

FIGURE 1

BUFFALO RIVER POLLUTION STUDIES

SAMPLING STATIONS



gen demand and bacterial tests and, in addition, sufficient sample for other tests. Sanitary chemical analyses, including biochemical oxygen demand, total and suspended solids, volatile matter, oxygen consumed, total nitrogen, turbidity, alkalinity or acidity, pH and iron, were made on each sample. Bacterial tests included total bacterial counts on agar at 37° C. and most probable numbers of coliform bacteria by serial dilution in lactose broth.

The total quantity of solids, oxygen demand, acidity or alkalinity, and coliform bacteria was calculated from the content and the gaged flow at the time of sampling. The findings resulting from the analyses of the river samples were used to show the variation in the condition of the river during the years 1936–39.

In addition to these biochemical surveys, studies were also made of the major industrial wastes discharged into the stream. Samples were

TABLE I.—*Location of Sampling and Gaging Stations*

Station	Location	Miles from Mouth of River
ON CAZENOVIA CREEK		
Gaging Station	Ridge Road Bridge	9.7
Station U	Cazenovia Park Bridge	7.1
Station T	Cazenovia Street Bridge	6.5
Station R	Bailey Avenue Bridge	5.6
ON BUFFALO CREEK		
Gaging Station	Harlem Road Bridge	8.5
Station S	South Ogden Street Bridge	7.5
Station Q	Bailey Avenue Bridge	5.6
JUNCTION OF BUFFALO AND CAZENOVIA CREEKS		5.5
Station J	D. L. & W. Railroad Bridge	5.2
Station P	South Park Avenue Bridge	4.6
Station O	N. Y. C. Railroad Bridge	3.5
Station N	Ft. of Katherine Street	2.6
Station M	Ohio Street Bridge	1.6
Station L	Michigan Avenue Bridge	0.9
Station K	Mouth of River	0.0

collected from, and flow gaged of, the individual sewers of each plant for 24 hours each day over a period of seven to fourteen days. Analyses were made on composite samples. A few studies were also made in cooperation with certain of the industries to ascertain possible means of waste treatment. All of the industrial studies were made in 1936 and 1937. The findings of these industrial investigations were used together with information on domestic sewage discharges in order to establish the quantity of pollution entering the river.

Tabulation and plotting of the survey data were done in a form which would make evident the effects of the interception of sewage, and the treatment or removal of some of the industrial wastes. In reporting the findings of these studies, it was apparent that in the case of this stream, the usual methods of interpretation could not be applied. The following complicating factors had to be taken into consideration:

1. The relation of the capacity of the dredged basin to the flow in the stream.
2. The effect of the rise and fall in the level of Lake Erie on the dredged basin.
3. The multiplicity of waste discharges and the distribution of these wastes along the entire length of the basin.

The following discussion amplifies these factors:

1. The capacity of the dredged basin was calculated to be approximately 165,000,000 cubic feet. With a normal dry weather flow of 125 c.f.s. in the late spring and early fall, and at times half of that in summer, it was calculated that the detention period was from 15 to 30 days during the warm months. At the minimum flows there was practically no movement of water in the basin, and the result was sedimentation and anaerobic digestion. Winter flows were high enough to prevent stagnation of the wastes.

2. Because the dredged basin was part of the harbor any change in the level of Lake Erie was accompanied by a similar change in water level throughout the entire basin. It was frequently observed that the water in the basin was actually flowing upstream, thereby holding the pollution out of the lake. Low lake levels caused a more rapid movement of water out of the basin than would be accounted for by natural flow. With this ebb and flow, it was to be expected that a diffusing and diluting effect of lake water would be noticeable near the mouth of the river. The diluting effect was observed at times to extend back as far as Station M, or a distanc of 1.6 miles from the mouth of the river.

3. Not only were the heavy industrial wastes added at several points between Stations J and O but the major portion of the sewage entering the stream was discharged at several outlets between Stations J and M, although some sewage entered both above and below these points.

Considering the interrelation of these three factors, it was obvious there were no one or two points in the whole basin that would serve as a station at which the pollution of this stream could regularly be measured. At the lower end of the basin, where all of the wastes were included, the diluting effects of lake water were noticeable. Upstream samples, at a single sampling station, would not include all of the wastes; they would also be affected by sedimentation and septic action, by ebb and flow, or both. Under certain conditions, the liquid located at one station on one day might be at the station above on the next day and vice versa.

Under these conditions, there were two methods of interpreting the data and both were used. In the first of these methods, the results at each station were averaged for the two periods, June, 1936, to June, 1938, inclusive, and July, 1938, to December, 1939, inclusive. Storm flows of over 600 c.f.s. were omitted from these averages. This method of interpretation shows an average condition existing at any station as a result of all the factors (except flood flows) which come into play at that particular point.

The second method of interpretation was to consider that between Stations J and L existed a large septic basin containing practically all of the wastes and relatively unaffected by ebb and flow of water at the discharge end. Thus, if the analyses of samples taken between those points (*i.e.*, Stations P, O, N, M) were averaged, the result would be an approximation of the average conditions existing in the most polluted section of this stream or basin. There undoubtedly may be objections to these methods, but the conventional means of interpretation did not appear to be applicable to conditions which apparently were without precedent. The methods used in reporting the data did offer a means of establishing the severity of the condition existing in the stream before and after the inauguration of sewage and waste treatment.

Extent of Pollution—1936–37

On the basis of studies made in 1936–37 of the major industries and domestic sewers discharging into the Buffalo River the attempt was made to estimate the pollution load. In some cases, where more than one study was made in a plant, it was found that the strength of waste varied from week to week. Daily maxima were occasionally exceptionally high. For the purpose of arriving at what might be considered the maximum load, the highest weekly average strengths of industrial wastes and the maximum discharge of sewage were used in the computation. Table II shows the total quantities of waste material entering the stream before July, 1938.

Table II.—*Wastes Entering Buffalo River in 1936–37*

Items	Domestic Sewage	Industrial Waste	Total
Flow—M.G.D.	15.0	54.[1]	69.
Suspended Solids lbs./day	21,000	30,000	51,000
Acidity as $CaCO_3$ lbs./day	−19,000	+97,000	+78,000
Iron as Fe lbs./day	—	14,100	14,100
Oil—lbs./day	—	1,000	1,000
Biochemical Oxygen Demand—Population Equivalent per day [2]	82,000	162,400	244,400

[1] Included cooling water pumped from the river and returned mixed with wastes.
[2] Based on 0.17 lb. 5-Day B.O.D. per capita per day.

Included in these industrial pollution loads were wastes from gas and coke, oil refinery, chemical, steel, malt and fertilizer plants. With very little flow during the summer months, the cause of septic conditions in the basin was obvious. At extremely low flows the pH of the upper basin was so low that corrosion damage was severe in some plants, using river water for cooling purposes. The dilution factor averaged less than one part of diluting water to one part of waste for five to six months of the year. The introduction of 50,000 pounds of suspended solids per day probably added to the possibility of sludge bank formation and the need for periodic dredging of the basin.

Analytical Results

In the presentation of the analytical findings, the unusual conditions existing in this stream were considered in accordance with the discussion above. The analytical data obtained from the several surveys have been summarized and averaged in Table III. This table shows the

Table III.—*Buffalo River Pollution Studies—Average Quantitative Results at Individual Stations*[1]

Station Miles from Mouth	Before July 1st, 1938						After July 1st, 1938					
	Flow c.f.s.	1000 lb./ day-Dis. Oxy.	1000 lb./ day 5-day B.O.D.	Q.U. Coli-form	1000 lb./ day Susp. Sol.	1000 lb./ day Alkty.	Flow c.f.s.	1000 lb./ day-Dis. Oxy.	1000 lb./ day 5-day B.O.D.	Q.U. Coli-form	1000 lb./ day Susp. Sol.	1000 lb./ day Alkty.
U+S 7.25	203	11.7	3.6	41	41.2	106	124	7.6	1.8	24.6	19.7	61.5
J 5.2	209	9.4	6.9	914	28.5	115	124	4.0	2.5	32.2	14.5	43.8
P 4.6	213	9.3	15.0	529	43.2	93.2	126	3.8	3.7	33.3	18.5	30.1
O 3.5	220	6.6	19.1	470	64.7	81.2	131	2.4	8.8	149.7	32.1	22.6
N 2.6	220	6.3	16.2	238	67.8	78.0	131	4.6	7.4	223.0	61.8	34.0
M 1.6	220	5.9	15.7	474	77.1	77.2	131	4.0	7.7	168.0	73.6	42.8
L 0.9	221	5.4	13.5	488	75.8	86.3	131	4.4	7.5	75.4	70.0	44.8
K 0.0	226	9.4	7.5	343	91.4	102	131	5.5	3.6	45.2	56.0	57.4
Avg. Stats. J to L incl.	217	7.15	14.4	519	59.5	88.5	129	3.87	6.27	114	45.0	36.3

[1] Averages do not include storm flow data of 600 C.F.S. or over.

average quantitative results at the individual stations before and after July 1, 1938. These averages do not include storm flow of over 600 c.f.s. The quantitative results were expressed as follows: flow in cubic feet per second; 5-day B.O.D., dissolved oxygen, alkalinity, and suspended solids in 1000 pounds per day; and coliform bacteria in quantity units—

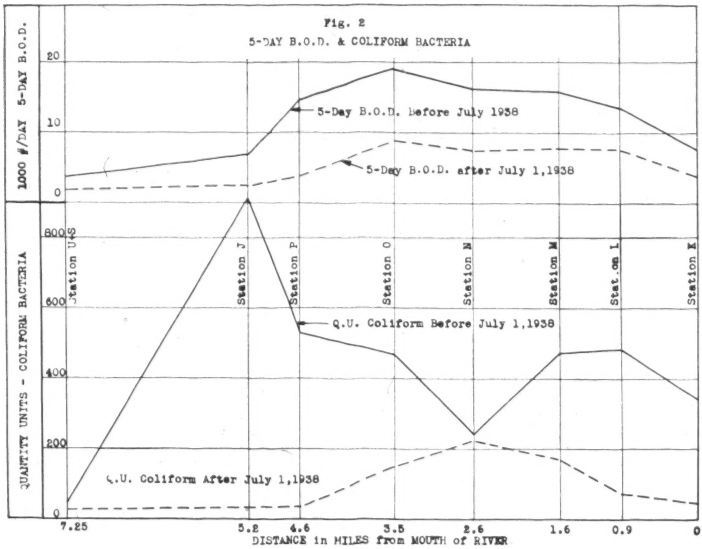
$$\frac{\text{(c.f.s.} \times \text{coliform per ml.)}}{1000}.$$

The flow in the stream after July 1, 1938 averaged approximately 58 per cent of the flow prior to that date. This was a climatological condition and did not reflect the removal of sewage from the stream. Average quantity of sewage removed was calculated to be 14 c.f.s. or approximately 6 per cent decrease from the period before July, 1938. The decrease in flow did affect at least two items, the quantity of dissolved oxygen and the quantity of alkalinity entering the basin. The quantity of suspended solids may likewise have been affected to some extent by this flow factor.

The most significant data in Table III are the 5-day B.O.D. and coliform content. These data are plotted in Fig. 2, which shows graphically the improvement in the condition of the stream. The B.O.D. of the stream entering the city was approximately the same in p.p.m. in both periods but the total was less after July, 1938 due to lower flow. From Station J to K (the mouth) the B.O.D. shows a decided improvement

after July, 1938. Not only was the total B.O.D. less but even at lower flow the p.p.m. of B.O.D. were less.

The coliform curves show decided improvement in condition. Before July, 1938, there was a rapid increase in coliform to Station J. This was caused by sewage discharges. The decrease in coliform content from Station J to Station N was due to the introduction of industrial wastes, some quite acidic. The pH in that section of the river varied from 2.6 to 5.4 in normal flows. Regrowth occurred below Sta. N. After July, 1938 there was an increase of coliform between Stations P and N in the industrial section. This may have been due in part to sanitary waste from the industries, as the removal of these



wastes was not all accomplished immediately. The increase may also have been due to a natural growth cycle occurring when the normal bacterial content reached the section of the basin wherein organic foodstuffs were available (pH conditions were more favorable in this period).

In order to estimate approximately the extent of general improvement in the stream the data in Table III were averaged for Stations J to L inclusive. This average omitted Sta. K (because it was affected by dilution from Lake Erie) and Stations U plus S because they were outside of the city. The average, therefore, represented the entire polluted basin.

In order to evaluate the improvement in conditions a correction of

these averages was made for the condition of the stream entering the basin. The computation was made as follows:

5-Day B.O.D.

	Before 7/1/38	After 7/1/38	Reduction	Per Cent Red.
Avg. Sta. J–L	14.4	6.27	8.13	56.5
Sta. U plus S	3.6	1.80		
Corr. Avg.	10.8	4.47	6.33	58.7

Coliform Content

	Before 7/1/38	After 7/1/38	Reduction	Per Cent Red.
Avg. Sta. J–L	519	114	405	78
Sta. U plus S	41	24.6		
Corr. Avg.	478	89.4	389	79.3

Inasmuch as the improvement in the stream entering the city was approximately 50 per cent, the correction does not appreciably affect the result. Generally it may be said that oxygen demand was reduced approximately 59 per cent and coliform bacteria approximately 79 per cent.

Correlation of conditions in the stream with pollution added was impossible due to the factors of sedimentation, digestion, reaeration, variation in flow and in strengths of waste added, and infrequent sampling. Not only was this apparent in the case of oxygen demand but also alkalinity and suspended solids. The following summary indicates the difficulties of balancing alkalinity data.

	Before July, 1938 1000 lb./day	After July, 1938 1000 lb./day	Red. 1000 lb./day
Alk. entering basin	106	61.5	
Minus min. alk. observed	77.2	22.6	
Diff.	28.8	38.9	
Plus alk. added as sewage	19.0	0.0	
Sum. equiv. to acid added	47.8	38.9	8.5

These data indicate neither the quantity of acid formerly discharged nor the reduction of losses known to have been accomplished. Inasmuch as a loss of 20,000 lb. per day was corrected in 1936 and more since then, it is estimated that these figures should be 77,000 and 30,000 respectively. Explanations for the discrepancy included (1) reaction with alkaline wastes of other plants, (2) reaction with alkaline suspended solids in the stream, and (3) reaction with alkaline diluting water from the lake. The latter explanation may be the most plausible because it was noted that from Sta. N to K the alkalinity increased and at Sta. K all acid effects were practically neutralized.

Suspended solids data were not easily explained. In general there appeared to be little improvement even though 20,000 pounds per day less were brought into the basin and waste and sewage solids were known to have decreased.

As mentioned above, the second method of interpreting the data was to consider the most polluted section of the basin as a unit embracing Stations P, O, N and M. This was done in Table IV which presents the average of the four stations by months, before and after July, 1938. Averages are given including and excluding storm flows of over 600 c.f.s. All data are presented in quantitative results.

TABLE IV.—*Conditions in Buffalo River-Average of Stations P, O, N and M*

Part A—Before July 1, 1938

Month	Flow c.f.s.	B.O.D. 1000 lb./Day	Dis. Oxy. 1000 lb./Day	Susp. Sol. 1000 lb./Day	Coliform Q.U.
1936					
June	86.0	10.9	0	34.9	20.9
July	43.1	10.0	0	17.1	78.2
August	32.3	10.0	0	11.3	49.2
September	29.6	9.4	0	14.5	122.
October	66.3	10.4	0	8.6	262.
November	790.	302.0	7.6	236.0	1127.
December	173.	27.7	3.9	50.3	160.
1937					
January	572.	36.4	33.7	139.0	847.
February	453.	34.2	26.3	113.9	247.
March	925.	45.2	55.7	177.0	967.
April	713.	12.9	37.2	877.0	907.
May	325.	14.9	1.0	94.2	816.
June	201.	8.8	0	57.6	1198.
July	161.	15.3	0	42.8	325.
August	83.	11.4	0	35.7	263.
September	111.	19.9	0	109.0	195.
October	627.	121.0	0	398.0	841.
November	454.	13.3	10.9	85.8	1739.
December	188.	20.0	8.8		313.
1938					
January	774.	29.3	52.5	159.0	964.
February	675.	34.1	43.0	2810.0	109.
March	576.	26.2	34.1	196.0	550.
April	315.	17.6	12.2	40.1	317.
May	161.	7.5	0.5	49.6	296.
June	112.	6.5	0	38.0	320.
Average incl. storm flows	346.	34.2	13.1	241.0	522.
Average excl. storm flows*	218.	16.3	6.9	63.2	428.

* Exclusive of storm flow data (600 c.f.s. or over).

TABLE IV.—*Continued*

Part B—After July 1, 1938

Month	Flow c.f.s.	B.O.D. 1000 lb./Day	Dis. Oxy. 1000 lb./Day	Susp. Sol. 1000 lb./Day	Coliform Q.U.
1938					
July	38.8	6.3	0	7.8	89.4
August	74.8	0.8	0.03	41.5	60.5
September	103.	3.5	0.3	47.0	1097.
October	62.8	7.6	0	20.0	26.9
November	164.	8.7	6.2	74.8	217.
December	198.	8.6	12.0	39.7	70.9
1939					
January	738.	24.8	47.1	230.	248.
February	652.	18.8	42.3	104.	28.7
March	477.	16.5	31.7	308.	146.
April	962.	32.7	61.5	700.	79.3
May	117.	9.2	0.3	30.9	115.
June	38.8	3.2	0	13.5	10.2
July	24.8	2.4	0	11.5	5.9
August	50.8	3.8	0	15.8	184.
September	21.8	3.2	0	5.7	3.8
October	55.8	6.5	0	16.4	26.6
November	239.	14.4	3.8	57.0	67.7
December	279.	13.2	15.2	149.4	58.4
Average incl. storm flows	239.	10.2	12.2	104.	145.
Average excl. storm flows	130.	7.2	4.6	56.0	145.

The data in this table were studied from the standpoint of seasonal effects on B.O.D. and coliform content. Seasonal divisions were only two; above and below a stream temperature of 10° C. June to November fell in the first class and December to May in the second. Most pronounced seasonal effects were absence of, or extremely low, D.O. in the warm months and increased B.O.D. in the cold season. Bacteria were about the same. Higher flows in the winter, which prevented sedimentation and concurrent anaerobic digestion, may partially explain the higher winter B.O.D.

Because the number of surveys was relatively few, and a disproportionate number of usable data occurred in the two seasons, the averages produced a fictitious value not amenable to comparison of conditions before and after on a seasonal basis. Generally speaking, however, it may be said that summer conditions improved slightly more than winter conditions as far as oxygen demand was concerned and vice versa, as far as coliform content was concerned.

Figure 3 shows the average dissolved oxygen content at these four stations in 1000 lb. per day and the temperature in degrees Cent. plotted by months. The temperature—dissolved oxygen relations follow the

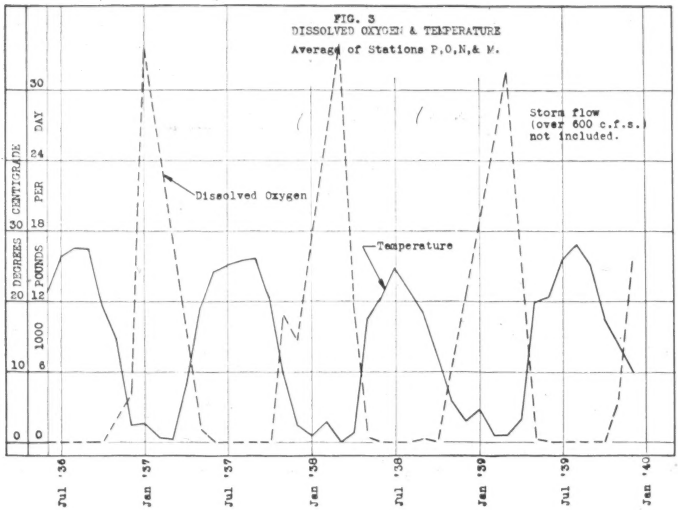


FIG. 3
DISSOLVED OXYGEN & TEMPERATURE
Average of Stations P,O,N,& M.
Storm flow
(over 600 c.f.s.)
not included.
Dissolved Oxygen
Temperature
DEGREES CENTIGRADE
POUNDS PER DAY
1000
30
24
18
12
6
0
20
10
Jul '36
Jan '37
Jul '37
Jan '38
Jul '38
Jan '39
Jul '39
Jan '40

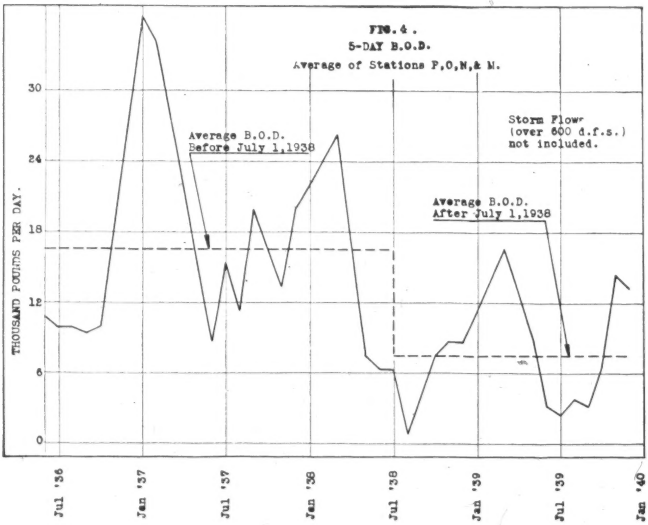
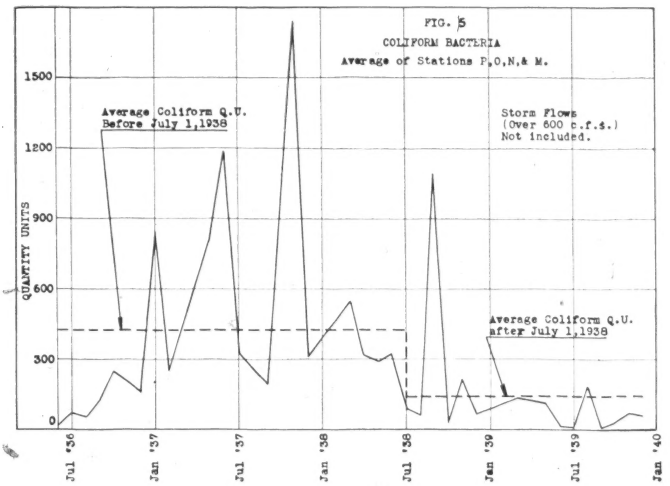


FIG. 4.
5-DAY B.O.D.
Average of Stations P,O,N,& M.
Storm Flow
(over 600 d.f.s.)
not included.
Average B.O.D.
Before July 1,1938
Average B.O.D.
After July 1,1938
THOUSAND POUNDS PER DAY.
30
24
18
12
6
0
Jul '36
Jan '37
Jul '37
Jan '38
Jul '38
Jan '39
Jul '39
Jan '40

familiar pattern of grossly polluted streams. Temperature rises were accompanied by a decrease in the dissolved oxygen content, and vice versa. It was observed on the seasonal basis that for 11 observations before July, 1938, the D.O. was zero for the warm months, but that for 11 observations for the same months after July, 1938, the D.O. averaged 940 pounds per day although at the same time the flow decreased, so that there was less dilution.

Figure 4 shows the average B.O.D. (1000 lb. per day) of the four stations plotted against time by months. Data for storm flows were omitted. The averages for the two periods (before and after July, 1938) graphically show the reduction in B.O.D. to be approximately 55.8 per cent. The choice of 600 c.f.s. as a criterion of storm flow was not



entirely arbitrary. It has been estimated (1) that normal year round average flow is approximately 650 c.f.s. On one observation (in March, 1939) a flow of 478 c.f.s. gave results very similar to previous storm flow data. Had the values for that month been omitted from the averages, the improvement in B.O.D. after July, 1938, would have been even greater than shown. The high B.O.D. in the latter part of 1939 occurred with extremely dry weather and little dilution.

Figure 5 shows the average coliform quantity units of the four stations also plotted by months. The low coliform content in the summer of 1936 was due to extremely acid conditions. (The pH was as low as 2.6.) The one extremely high datum point for September, 1938, was not readily explainable. Were it left out of the average after July, 1938, the improvement in bacterial conditions in the stream would be 83 per cent instead of 66 per cent as calculated from Table IV.

Data on the conditions in Buffalo Harbor also were collected at the same time as the river surveys were made. Some parts of the harbor received raw sewage; other parts were affected by the Buffalo River. No data are presented here, but it may be stated that improvement was observed in proportion to the removal of sources and causes of pollution. Swimming became popular at points formerly affected by the discharge of the Buffalo River. Silt deposits were decreased.

Soil Erosion

The subject of soil erosion in the drainage area of the Buffalo River and tributary streams was not studied per se but some interest has been shown in the amount of soil indicated to be carried into the dredged basin.

Table III shows that excluding storm flows, there were brought into the dredged basin an average of 20,000 to 40,000 pounds of suspended matter per day. Under the flow conditions existing for these averages, the detention period in the basin was from 9 to 15 days, and the average velocity through the basin was from 2.3 to 1.3 feet per minute.

S. A. Greeley (1), using U. S. Geological Survey Gagings on Cattaragus Creek as a basis, calculated the discharge of the Buffalo River to be

Annual Average	650 c.f.s.
Average May 1 to Oct. 31	355 c.f.s.

The data in Table IV showed the average discharge for 43 observations, including storm flows, to be 346 c.f.s. before July 1, 1938, and 239 c.f.s. after that time.

That there was some sedimentation of silt under these conditions was apparent from Table III comparing Stations U plus S and Station J. Below Station J wastes introduced affected the data in such a manner as to prevent estimation of the amount of sedimentation. Before July 1, 1938, the amount of suspended matter introduced from wastes was calculated to be 51,000 lb. per day. After that date this quantity was estimated to be 27,000 lb. per day. Although suspended solids introduced were less in the latter period, the amount of suspended matter in the lower end of the basin did not appear to be greatly improved.

Calculations were made on the suspended solids entering and leaving the basin under conditions including the flood flows. These data are shown in Table V.

It is illogical to assume from these data that since the sedimentation was less than the introduction of waste solids, there would be no sedimentation if the wastes were all removed. If Greeley's (1) flows more nearly represent average conditions, then the amount of suspended solids entering the basin, based on the above data, would average between 167,000 and 410,000 lb. per day.

TABLE V.—*Data on Sedimentation*

	Before July 1, 1938	After July 1, 1938
Flow	346 c.f.s.	239 c.f.s.
Detention period	3.5 days	8 days
Velocity	3.7 ft. per min.	2.5 ft. per min.
Susp. solids entering basin	218,000 lbs. per day	61,500 lbs. per day
Susp. solids added in basin	51,000 lbs. per day	27,000 lbs. per day
TOTAL SUSPENDED SOLIDS	269,000 lbs. per day	88,500 lbs. per day
Susp. solids leaving basin	225,000 lbs. per day	70,000 lbs. per day
SEDIMENTATION	44,000 lbs. per day	18,500 lbs. per day

INDUSTRIAL COOPERATION

Reference has been made to the industrial studies of 1936 and 1937. In addition to these studies, conferences were held with representatives of each of the major industries discharging waste into the river and the many problems involved were discussed.

In November and December, 1937, three episodes of fish poisoning occurred in the Niagara River. The exact lethal agent causing the poisoning was not determined but the source of the poison was traced to the Buffalo River. A complete report on these occurrences was published in the Transactions of the American Fisheries Society (2). Following these regrettable episodes, a meeting of the industries, the Sewer Authority and others, was called by the New York State Departments of Health and Conservation to discuss the problems of industrial pollution of the Buffalo River. The seriousness of the conditions was clearly presented and cooperation of the industries with the Authority was assured.

Since that time there has been a considerable expenditure of money and effort by several of the industries on ways and means of removing pollution from the river. From reports of the industries on expenditures and analysis, an estimate of progress toward a cleanup of industrial wastes has been made.

The 5-day B.O.D. population equivalent of the major industrial wastes was reduced by 63,000 during the first year of active effort, a decrease of approximately 40 per cent. Acids losses were reduced over 60 per cent. Iron wastes were reduced by more than half. Oil losses, suspended solids, and phenols were reduced. Expenditures by industry have been estimated to be in excess of $125,000 on anti-pollution efforts.

New problems continue to arise in many of the industries but the spirit of cooperative effort is best exemplified in these words abstracted from one report, "one of the new products would have added to the Buffalo River a B.O.D. population equivalent of 32,000 and a calcium carbonate acid equivalent of 9,800 lb. per day, had not remedial steps been taken in advance to revise original process specifications."

SUMMARY AND CONCLUSIONS

This stream pollution study of the Buffalo River for a period of 45 months from April, 1936, to December, 1939, has produced a variety of

data and information. It was developed that stream flow conditions were quite low and subject to fluctuating lake levels and that dredging had produced a basin capable of holding several days normal dry weather flow. Under these conditions it was impossible to interpret the data in the usual manner. It was necessary to consider the stream almost as a pond. It was apparent that more frequent sampling would have been advantageous. Since weekly sampling was not possible the data had to be considered over relatively long periods of time. From these studies several facts were developed as follows:

1. Prior to July 1, 1938, on which date sewage treatment was inaugurated in Buffalo, this stream was grossly polluted, receiving as it did sewage and industrial wastes equivalent to approximately 244,400 persons in addition to acids, iron and other wastes.
2. Since July 1, 1938, sewage of approximately 82,000 persons and industrial wastes equivalent to approximately 63,000 persons have been removed from the river. (Sanitary waste from approximately 4,000 industrial employees has been eliminated from the river.)
3. Biochemical oxygen demand tests indicate an improvement in the river of approximately 57 per cent since July, 1938.
4. Bacterial tests indicate a reduction of approximately 75 per cent of the coliform bacterial content in the river.
5. Approximately $125,000 has been spent on industrial waste cleanup and industrial cooperation has been evident.
6. Data on suspended solids indicate considerable soil erosion on the drainage area.
7. Additional studies and treatment of industrial waste will be necessary to complete the cleanup program.

Acknowledgment

The Bird Island Laboratory is indebted to the New York State Departments of Health and Conservation for their assistance in conferences with the industries concerned; to the representatives of the industrial concerns for their cooperation in the studies of the industrial waste load; to Greeley and Hansen, Engineers for the Buffalo Sewer Authority, for assistance in establishment of the gaging stations and the inauguration of the program of study. Acknowledgment is due to Mr. R. W. Simpson for making the bacterial analyses; to Mr. C. G. Ketcham for collection of samples, and to Mr. J. R. Rumsey of Greeley and Hansen, for critical advice on the presentation of the data.

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Industrial Wastes

SOME EFFECTS OF SULFUR DYE WASTE UPON SLUDGE DIGESTION

By Ralph Porges,[1] Henry J. Miles,[2] and Herman G. Baity [3]

[1] *Special Investigator*, Textile Foundation—University of North Carolina Textile Waste Research Project; [2] *Former Special Investigator*, Textile Foundation—University of North Carolina Textile Waste Research Project; and [3] *Professor of Sanitary Engineering*, Division of Public Health, *University of North Carolina*

Industrial wastes discharged into municipal sewage treatment plants are creating many problems, especially so when strong discharges such as textile wastes are received. Indications point to an increase in such combined treatment for industrial wastes. In order to provide basic information regarding the possibility of handling textile wastes in combination with domestic sewage in joint treatment works, the Textile Foundation, in cooperation with the University of North Carolina, is carrying on experimentation on those treatment processes adversely affected by such wastes.

Many textile wastes received by sewage disposal systems are toxic to biological processes and may have a detrimental effect on sludge digestion. Since sulfur dye waste is one of the strongest textile waste liquors, it was selected for study with the objective of making the following determinations:

1. The effect of sulfur dye waste upon sludge digestion.
2. The effect of digesting activated sludge derived from a dye-sewage mixture.
3. The possibility of the acclimatization of methane producing bacteria.
4. The effect of various amounts of seed sludge upon the digestion of dye-sludge mixtures.

General Technique

Apparatus.—Since the rate and quantity of gas production and the composition of the gas are significant measures of the efficiency of a digesting process, the following apparatus was constructed for ascertaining and comparing the gas production of the digesting mixtures in a parallel series of containers:

One-gallon bottles were employed as digestion chambers. Each bottle had a one-hole stopper through which passed a glass tube attached to rubber tubing leading to individual gas holders constructed of calibrated cylinders. All joints were sealed to prevent gas leakage and air infiltration. The volume of the gas evolved was measured by liquid dis-

placement. In order to minimize errors caused by the solubility of the gases in water, gas-saturated water was used in all cases. A diagrammatic illustration of the digestion apparatus is presented in Fig. 1.

These digestion chambers were maintained at 82° F. in a thermostatically controlled chamber, the optimum temperature for mesophilic digestion. The gas holders stood outside the incubator necessitating daily recordings of temperatures along with barometric pressures in order to correct for volume variations of the confined gases. All gas recordings are given at standard conditions (0° C., 760 mm. Hg).

Materials.—Digested sludge was obtained from the Chapel Hill sewage treatment plant, activated sludge from the Durham Northside plant, and dye waste from the Proximity Print Works, Greensboro,

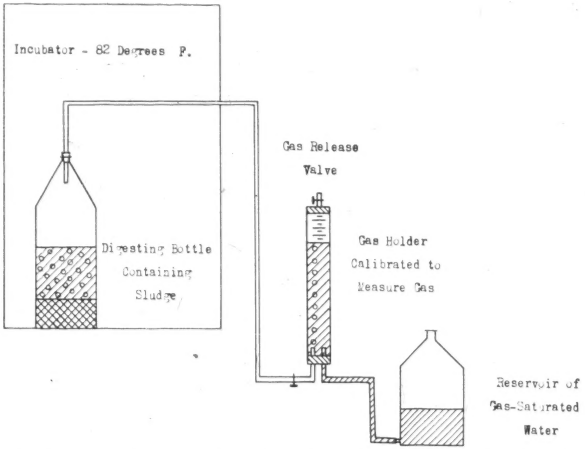
Incubator - 82 Degrees F.
Gas Release Valve
Digesting Bottle Containing Sludge
Gas Holder Calibrated to Measure Gas
Reservoir of Gas-Saturated Water

FIG. 1.—Diagrammatic presentation of experimental apparatus for digestion studies.

N. C. The dye waste consisted of concentrated sulfur black dye liquor as discharged from the dyeing machine; it had a deep blue-black color, a pH of 11.4 and 4.38 per cent solids with 33.8 per cent volatile matter.

Activated sludge obtained by treating a dye-sewage mixture was prepared in an experimental unit. The experimental aeration unit consisted of a 6 gallon crock aerated by compressed air supplied through a short section of a four-inch diameter diffuser tube mounted at the end of a ½ in. pipe. This unit was operated on a mixture of unsettled, screened sewage from the Chapel Hill disposal plant and dye waste liquor. The untreated activated sludge utilized to start the experimental unit was obtained from Durham. After the activated sludge-dye waste-sewage mixture was aerated for 22 hours and then settled for one hour, the supernatant layer was removed and replaced by a dye-sewage mixture of the concentration desired, which will be indicated

later. This aeration, sedimentation, removal, and replacement was carried out a specific number of times before concentration and removal of portions for experimentation.

General Procedure.—This experiment was conducted in two parts so that acclimatized digested sludge from Group I could be used. Group I consisted of 9 one-gallon bottles each containing one liter of digested sludge and one liter of activated sludge. The digested sludge of Group I contained 6.61 per cent total and 52.4 per cent volatile solids. As shown in Table I, increments of dye were added to Bottles 2 to 8 inclusive while No. 1 was left as control. Activated sludge used in Bottles 1 to 8 contained 0.82 per cent total and 71.5 per cent volatile solids. To obtain sludge derived from treating a dye-sewage mixture for Bottle 9, the aeration unit was operated with one gallon of activated sludge mixed with four gallons of screened sewage to which had been added two per cent (310 ml.) of dye waste. Fresh sewage-2 per cent dye waste mixtures were added on three successive days. Sludge was then concen-

TABLE I.—*Contents of Digestion Bottles With Increments of Dye-Waste (Group I—Bottles 1 Through 9)*

Bottle No.	Digested Sludge	Activated Sludge	Dye Waste by Volume	
			Ml.	Per Cent
1	1 liter	1 liter	0	0
2	1 liter	1 liter	10	0.5
3	1 liter	1 liter	20	1.0
4	1 liter	1 liter	30	1.5
5	1 liter	1 liter	40	2.0
6	1 liter	1 liter	50	2.5
7	1 liter	1 liter	60	3.0
8	1 liter	1 liter	120	6.0
9	1 liter	1 liter*		

* Activated sludge from experimental unit treating a 2 per cent dye-sewage mixture.

trated to 2165 ml. and one liter added to one liter of ripe sludge and digested as Bottle 9 (Table I).

The ripe sludge from the various bottles of Group I were utilized for Group II which included digestion Bottles 10 through 17. Bottle 10, control for Group II, contained activated sludge from Durham and ripe sludge from Bottle 1, control of Group I. Bottles 11 and 12 digested activated sludge from Durham and ripe sludge composited from Bottles 2 to 8. In addition there was added to Bottles 11 and 12 three and six per cent of dye waste, respectively.

Activated sludges from dye waste-sewage mixtures were obtained by again operating the experimental unit as follows:

Four gallons of 2 per cent dye waste-sewage mixtures were added on the first, second and fourth days. After concentration of sludge to 2790 ml. sufficient sludge was removed for Bottle 13 after which the operation of the experimental aeration unit was continued with a 4 per

cent dye waste-sewage mixture on the fifth, sixth, and seventh days. After concentration, enough sludge was removed for Bottle 14, after which a 6 per cent dye waste-sewage mixture was treated on the seventh and ninth days. The resulting sludge was concentrated to 2000 ml. and used in Bottles 15, 16, and 17.

The proportioning, origin and analyses of both ripe and activated sludges are given in detail in Table II.

TABLE II.—*Contents of Digestion Bottles Using Varying Amounts and Kinds of Digested and Activated Sludge and Dye Waste (Group II, Bottles 10 through 17)*

Bottle No.	Digested Sludge				Activated Sludge				Dye Waste by Volume	
	Volume in Ml.	Origin	Solids		Volume in Ml.	Origin	Solids		Ml.	Per Cent
			Total	Volatile			Total	Volatile		
10	400	Bottle No. 1	3.27	50.8	1600	Durham	0.69	70.6	0	0
11	400	Composite Bottles No. 2–8	3.10	50.9	1600	Durham	0.69	70.6	60	3
12	400	Composite Bottles No. 2–8	3.10	50.9	1600	Durham	0.69	70.6	120	6
13	200	Bottle No. 9	3.27	51.6	800	Treatment 2% dye-sewage	0.96	66.5		
14	200	Bottle No. 9	3.51	50.7	800	Treatment 4% dye-sewage	1.66	67.0		
15	450	Composite Bottles No. 2–8	7.79	50.1	450	Treatment 6% dye-sewage	1.25	65.6		
16	300	Composite Bottles No. 2–8	7.79	50.1	600	Treatment 6% dye-sewage	1.25	65.6		
17	180	Composite Bottles No. 2–8	7.79	50.1	720	Treatment 6% dye-sewage	1.25	65.6		

The following tests and observations were made: total solids and volatile solids before and after digestion; gas evolution recorded daily and occasionally analysed; and temperature and barometric pressures, recorded daily. In all cases, solid determinations were made on the individual sludges and mixtures of sludges. The solids of the dye waste were added to the determination of the mixtures so that all given data includes the solids of the dye.

DISCUSSION OF RESULTS

Effect of Direct Addition of Dye Waste Upon Sludge Digestion.—The results of digesting one liter of activated sludge and one liter of

ripe sludge with increments of dye waste are compiled in Table III. The cumulative gas production per gram of volatile solids added is pre-

TABLE III.—*The Effect of Sulfur Dye Waste Upon Sludge Digestion*
(Summary of Results of Bottles 1 to 8)

Bottle No.	Per Cent Dye	Ratio of Fresh Solids to Ripe Sludge on Basis of Volatile Matter	Total Solids		Volatile Solids			Volatile Solids Added in Fresh Sludge, Grams	Gas per Gram Volatile Matter Added, c.c.	Methane at End of Digestion Period, Per Cent
			Beginning Digestion, Grams	End of Digestion, Grams	Beginning Digestion, Grams	End of Digestion, Grams	Destroyed, Grams			
1	0	1–5.88	68.8	65.4	37.90	33.2	4.2	5.88	652	80.6
2	0.5	1–5.73	69.24	66.0	38.05	33.9	4.15	6.03	585	68.0
3	1.0	1–5.60	69.68	66.0	38.20	32.35	5.85	6.18	550	68.0
4	1.5	1–5.46	70.14	66.2	38.25	33.50	4.85	6.33	521	69.7
5	2.0	1–5.34	70.54	66.1	38.49	34.00	4.49	6.47	468	69.6
6	2.5	1–5.23	70.99	67.2	38.64	34.30	4.34	6.62	430	62.7
7	3.0	1–5.11	71.43	67.6	38.79	34.40	4.69	6.77	388	63.0
8	6.0	1–4.23	74.06	70.4	39.68	35.40	4.28	7.66	329	73.6

sented graphically in Fig. 2. These have been adjusted to 0° C. temperature and 760 mm. mercury barometric pressure.

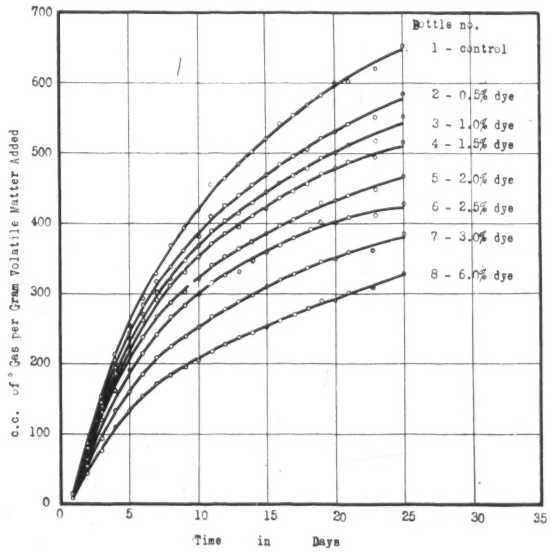

FIG. 2.—Gas production in digesters as influenced by increments of dye waste.

It is obvious that sulfur dye waste under the condition of this experiment had an inhibitory effect upon sludge digestion; as low a concen-

tration as 0.5 per cent dye waste decreased gas evolution and methane production. Increasing the quantities of waste further reduced gasification with the result that in 25 days the 6 per cent dye waste-sludge mixture produced only 50 per cent as much gas as the control, although liquefaction was retarded only slightly. Worth and Baity (2) digesting combined sludge and textile waste concluded that sulfur black dye liquor-sewage sludge mixtures of 1 to 2 ratio by volume entirely prevented digestion; 1 to 15 ratio retarded for 20 days, and then accelerated, digestion; 1 to 60 ratio accelerated digestion in the initial stages. The waste used in the present study was evidently much stronger as, comparable to the 1 to 60 mixture, the 1.5 per cent dye waste-sludge mixture (Bottle 4) retarded gas production so that in 25 days only 80 per cent gas was produced as compared to control. Rudolfs and Lacy (1) digesting a ripe sludge-fresh solids mixture containing dye waste from the manufacturing of aniline dye proportioned according to flow found that gas production lagged and that the general retardation of digestion necessitated larger digestion capacity. Likewise, Rudolfs and Setter (3) studying the effect of certain organic wastes found that digestion was retarded somewhat by wool-scouring wastes and gasification was slower with rug dye waste. In all cases, the addition of waste caused increased production of H_2S. Likewise, the sulfur dye found in the waste used in the present study being an organic derivative, offers similar difficulties. H_2S was noticeable after digestion by the odors produced, and elemental sulfur was evident by the milky appearance of the supernatant liquor. This condition is aggravated by the Na_2S used in the make-up of the dye bath.

On the other hand, an unpublished report by Worth and Baity (4) on experimental work conducted at Durham states that a composite of the combined textile and domestic wastes from Durham, N. C., proportioned according to flow data obtained from studies at Durham, did not noticeably affect digestion of sludge. It appears therefore that if dye wastes are diluted sufficiently with sewage or sludge, the deleterious effect of the waste may be overcome. It is also possible that under such conditions the alkalinity of the waste may aid the initial stages of digestion and cause an initial acceleration in gas production as reported by Worth and Baity (2).

Conclusions.—Sulfur dye waste is detrimental to sludge digestion, as measured by gas production, in concentrations as low as 0.5 per cent by volume and the methane content of the gas is reduced in all cases. Evidently those organisms causing gasification are inhibited, as liquefaction is influenced but lightly by such waste. Gasification may not be materially reduced if the concentration of dye waste were decreased below the value used in this experiment.

Effect of Digesting Activated Sludge Derived From a Dye-sewage Mixture.—Should the activated sludge process act upon some of the constituents of the dye waste, a different action upon the digestion of sludge may result.

Accordingly, activated sludge was submitted to 2 per cent dye waste-

sewage doses on three successive days. As previously stated, four gallons of sewage with 310 ml. of dye waste consisted of the daily dose. Assuming that 75 per cent removal of color was obtained (estimate based on results of previous work (6)), the sludge contained, after three days, the color, or dye portion from 700 ml. of dye waste. This sludge was concentrated to 2165 ml., of which one liter was mixed with one liter of ripe sludge and designated as Bottle 9 in Tables I and IV. The coloring matter digested in two liters, then, was that amount removed from 323 ml. of dye waste. Therefore, the amount of dye treated by this method was approximately 16 per cent.

The same general procedure was followed for the contents of Bottles 13, 14, and 17 to obtain activated sludges from treating dye waste-sewage mixtures and are compared with Bottles 10 and 11 (illustrated in Fig. 3*b*), since in these bottles one part of digested sludge was used to seed four parts of fresh activated sludge. The contents of these bottles are shown in Tables I and II, while Table IV contains a summary of results, and Figs. 3*a* and 3*b* are the results of the cumulative

TABLE IV.—*The Effect of Digesting Activated Sludge Derived From Dye-Waste Mixtures (Summary of Results of Bottles 9–13–14–17)*

Bottle No.	Ratio of Fresh Solids to Ripe Sludge on Basis of Volatile Matter	Total Solids		Volatile Solids			Volatile Solids Added in Fresh Sludge, Grams	Gas per Gram Volatile Matter Added, c.c.
		Beginning Digestion, Grams	End of Digestion, Grams	Beginning Digestion, Grams	End of Digestion, Grams	Destroyed, Grams		
9	1 –4.23	78.15	70.4	42.78	37.4	5.38	8.18	390
13	1.51–1	14.5	11.4	8.7	6.03	2.67	5.1	168
14	2.5 –1	19.2	16.5	11.8	9.2	2.6	8.9	18.4
17	1 –1.19	20.61	19.44	11.8	10.75	1.05	5.9	12.9

gas production per gram of volatile matter added, presented graphically.

The aerated mixture in Bottle 9 (Fig. 3*a*) showed an initial lag and then accelerated slightly to produce approximately the same quantity of gas as the 3 per cent dye waste-sludge mixture. Based on the assumption that the coloring matter digested was that obtained from 16 per cent dye waste, more dye waste may be treated when removed from the sewage by activated sludge. However, gas production as compared to the control was retarded. Similar results were observed in Group II (Fig. 3*b*) with Bottles 13, 14, and 17 where the initial lag was very pronounced and gas production reduced. Destruction of solids was also retarded but not so completely as was gas production. Bottle 13 digested the coloring matter from about 20 per cent dye waste and, in spite of the large dye content, compares favorably to the 3 per cent dye waste-sludge mixture, Bottle 11. Bottles 14 and 17 contained coloring matter from large volumes of dye waste and the effect was such as to inhibit gasification.

The initial lag seems to be characteristic of the digesting activated sludge samples obtained from treating dye waste-sewage mixtures. This period of adjustment appears to be eliminated by the direct ad-

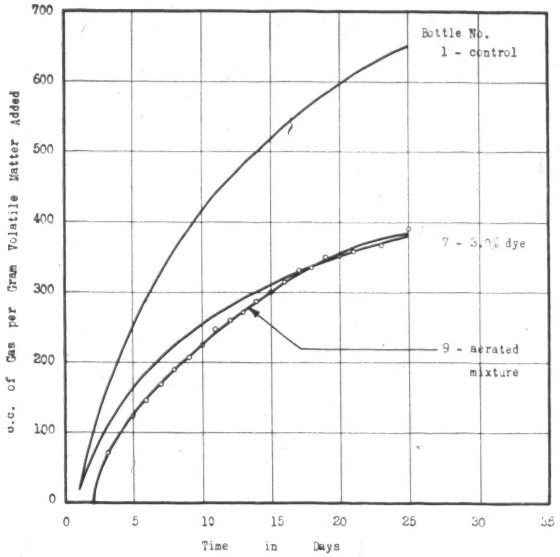

FIG. 3*a*.—Comparison of gas production between a control, 3 per cent dye waste mixture and activated sludge obtained from a 2 per cent dye-sewage mixture.

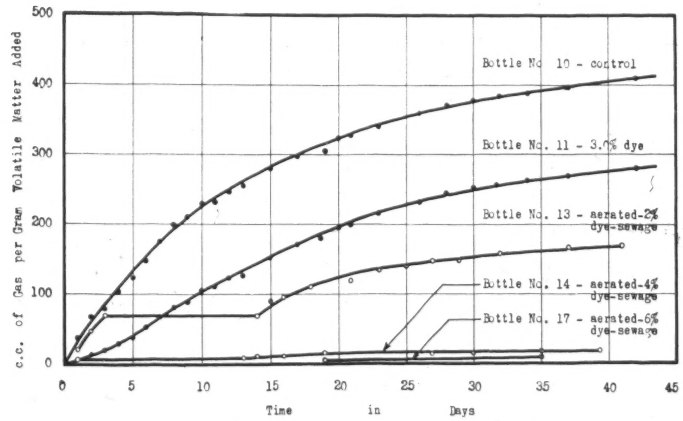

FIG. 3*b*.—Comparison of gas production between control, a 3 per cent dye waste-sludge mixture and sludges obtained from treating various dye-sewage mixtures.

dition of the dye to the digesting mixtures probably by the alkalinity of the dye waste.

Conclusions.—Results indicate that the coloring portion of the dye waste removed by the activated sludge process is harmful to the digesting process but less detrimental than the dye waste added directly to the digestion tanks. This may be attributed to the change in the dye waste brought about by the activated sludge process. The detrimental effect of sulfur dye waste on sludge digestion appears to be caused both by the properties of the dye itself and by the materials contained in the make-up of the dye vat.

Effect of Acclimatization on Sludge Digestion.—It has been observed by Rudolfs that "If on repeated additions, using as seed the ripe sludge produced previously, when the same quantity of waste was added, the observed retardation was reduced or overcome, a tendency to acclimate would be indicated" (5). The phenomenon of acclimatization seems to depend upon the ability of organisms in the sludge to adjust themselves to adverse conditions and is a characteristic of adaptation that some organisms have to adjust themselves to given conditions and survive. It has been found (5) that acclimatization is favorable toward most substances. In the general problem of textile waste disposal it is important to know if sludge digesting organisms may become acclimatized to the waste.

To note if such adaption is possible, the digestion bottles in Group II, Nos. 10 to 17 inclusive, were seeded with ripe sludge produced by Group I. As the sludge in Group I had been subjected to the dye waste, any acclimatization or adjustment would appear in a comparison of similar conditions between Groups I and II. Such comparisons are made in Table V using as the unit the amount of gas produced in 25 days per gram of volatile matter added. Variation between the two runs are wide even in the controls, indicating that the amount and condition of the sludge which contained 6.61 per cent total and 52.4 per cent volatile solids in Group I and 3.27 per cent total and 50.8 per cent volatile solids in Group II had a marked influence upon gas production. However, by referring each result to its corresponding control, a clearer picture is obtainable.

Bottles 9 and 15 (Table V) although producing less gas than the control, show, however, that by using acclimatized sludge more gas is produced—an indication of better digestion—even though much larger quantities of dye waste are present. This is further illustrated by Bottles 7 and 11 which contained 3 per cent dye waste on a volume basis and Nos. 8 and 12, containing 6 per cent. However, on a total solids basis, No. 7 had 3.68 per cent waste and No. 8, 7.09 per cent, while Nos. 11 and 12, using acclimatized sludge, contained 10.1 and 18.3 per cent respectively. Thus it is seen that 3.68 per cent dye waste produced only 59.5 per cent as much gas as the control and 7.09 per cent dye only 50.5 per cent; whereas with acclimatized sludge, 10.1 per cent produced 64.3 per cent as much gas as the control. Evidently 18.3 per cent dye waste exceeded the tolerance limit of the sludge digesting process.

TABLE V.—*The Effect of Acclimatization Upon the Digestion of Dye-Sewage Mixtures*

Bottle No.	Waste	Ratio of Fresh Solids to Ripe Sludge on Basis of Volatile Matter	Total Solids of Mixtures, Grams	Dye			Gas in 25 Days per Gram Volatile Matter Added	Gas Produced as Per Cent of Control	Remarks
				Per Cent by Volume	Total Solids, Grams	Per Cent on Basis of Total Solids			
1	Control	1–5.88	68.8	0	0	0	652	100	Group I
7	3 per cent dye	1–5.11	71.43	3	2.63	3.68	388	59.5	Group I
8	6 per cent dye	1–4.52	74.06	6	5.25	7.09	328	50.5	Group I
10	Control	1.17–1	24.10	0	0	0	354	100	Ripe sludge from Bottle 1
11	3 per cent dye	1.38–1	26.10	3	2.63	10.1	227	64.3	Ripe sludge Bottles 2 to 8
12	6 per cent dye	1.52–1	28.71	6	5.25	18.3	33	9.3	Ripe sludge Bottles 2 to 8
9	Aerated, 2 per cent	1–4.23					390	59.9	Group I
15	Aerated, 6 per cent	1–4.75					233	65.9	Ripe sludge from Bottle 9

Conclusions.—Sludge digesting organisms have a tendency to become acclimatized to sulfur black dye waste and indications are that if the concentration of dye is not excessive, such adjustment results in better digestion. It appears that the introduction of dye waste will lower gas production, however, this detrimental effect may be reduced to a minimum by the introduction of a constant dosage of waste so that acclimatization may become stabilized.

Effect of Various Amounts of Seed Sludge Upon Digestion.—Seeding is the use of digested sludge so as to introduce into, or "seed," the fresh sludge with the proper organisms and buffers. This method of retaining suitable ripe sludge greatly reduces the digestion time. Activated sludge obtained from treating a 6 per cent dye waste-sewage mixture was seeded with sludge so that on a volume basis, ripe sludge to fresh sludge, ratios of 1:1, 1:2, and 1:4 were obtained. Other

TABLE VI.—*Effect of Increasing Amounts of Seed Sludge Upon Digestion of Sludge Obtained by Aerating a 6 Per Cent Dye-Sewage Mixture*

Bottle No.	Sludge		Ratio of Fresh Solids to Ripe Sludge on Basis of Volatile Matter	C.c. of Gas Produced per Gram Volatile Matter Added, 35 Days	Remarks
	Digested, Ml.	Activated, Ml.			
15	450	450	1–4.75	258	Activated sludge derived by treating a 6 per cent dye-sewage mix
16	300	600	1–2.75	87	Activated sludge derived by treating a 6 per cent dye-sewage mix
17	180	720	1–1.19	12.9	Activated sludge derived by treating a 6 per cent dye-sewage mix

pertinent data are given in Table VI and cumulative gas production per gram of volatile matter added is plotted in Fig. 4.

The results indicate that one of the most important factors in the digestion of dye-laden sludge is the matter of seed. Bottle 15, containing the largest amount of seed sludge, produced 258 c.c. of gas per gram volatile matter added, while No. 16, with less seed sludge, recorded 87 c.c., and No. 17, with the least amount of seed sludge, 12.9 c.c. of gas. Comparing Bottle 15 (Fig. 4) to No. 13 (Fig. 3*b*) shows that the lag characteristic of digesting sludges obtained from dye waste-sewage mixtures had been greatly reduced by increasing the amount of seed sludge despite the fact that sludge in No. 15 was obtained from treating a 6 per cent dye waste-sewage mixture. Another consideration to be noted is that seed sludge is a diluent for the dye waste. As the seed sludge increases, the percentage of dye waste decreases. Referring to Table V,

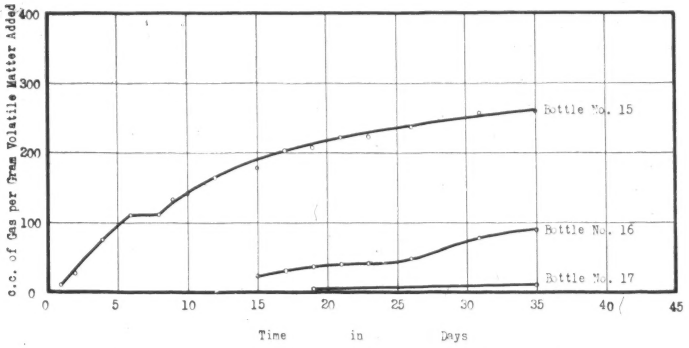

FIG. 4.—Gas production by varying the amounts of seed sludge.

the dye waste increases from 3.68 to 10.1 per cent, and from 7.09 to 18.3 per cent, merely by decreasing the seed sludge in Bottles 11 and 12 in respect to Bottles 7 and 8.

Conclusions.—The amount of seed sludge to be retained in a digestion tank is most important when trade wastes such as sulfur dyes are present in large quantities. With sufficient ripe sludge as seed material, initial lag in gas production is reduced and larger quantities of dye are tolerated. Therefore, such increase of seed sludge necessitates an increase in the design capacity of the digestion tank.

SUMMARY

Experimental batches of dye waste, activated sludge, and ripe sludge mixtures were incubated at 82° F. in one-gallon glass bottle digesters to obtain information as to the effect of sulfur black dye waste upon sludge digestion. Gas production and variations in solids were determined.

It has been shown that:

1. Sulfur black dye waste as low as 0.5 per cent by volume is detrimental to sludge digestion as measured by gas production and that concentrations above 6 per cent virtually stop gas production.
2. Dye waste added directly to the digesting mixture is more detrimental than dye waste removed from sewage by the activated sludge process and it is both the dye itself and the materials used in the dye vat that appear to retard gas production.
3. Sludge digesting organisms are able to be acclimatized to sulfur black dye wastes, and such acclimatized seed sludge aids in digesting larger quantities of dye waste in a shorter period.
4. Proportioning is very important since with large quantities of seed sludge, the initial lag in gas production is reduced to a minimum and larger quantities of dye waste are tolerated.

Acknowledgment

Appreciation is expressed to Dr. Willem Rudolfs of the New Jersey State Experiment Station for his helpful comments.

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Operators' Reports and Suggestions

W. D. Hatfield

249 Linden Place, Decatur, Ill.

CERTIFICATION *

By C. T. Mudgett

Sewage Treatment Works, Muskegon, Mich.

New Jersey was the pioneer in certification of sewage plant operators. It has a legislative act passed in 1918 by the New Jersey State Legislature. This Act authorizes the State Department of Health to:

1. Make rules for examining applicants for sewage and water plant operators to determine their qualifications and issue licenses.
2. Make it compulsory that every plant have in responsible charge a licensed operator.
3. Revoke licenses for incompetency.
4. Inflict a penalty of $10 per day on any person violating any provision of the Act. A "Grandfathers Clause" was included.

The Health Department rules are lengthy and will not be given in detail. They include: a $5 fee for applicants, an annual renewal fee of $5 for holders of licenses, a clause prohibiting any one person from operating more than one plant except by permission, and the classification of sewage treatment plants into eight separate grades. The experience qualifications for applicants varies from six years to two years for plants with capacities exceeding 0.25 M.G.D. and for plants with smaller capacities and the effluent not affecting potable water supplies or shell fish beds, experience satisfactory to the State Department of Health. Allowance for education varies from one to five years.

New York has regulations not familiar to the writer.

Ohio has regulations adopted August 1, 1937, by the Public Health Council of the State Department of Health. These regulations provide: that all plants, water purification and sewage treatment, be placed under the supervision of certified operators; that the Director of Health shall make necessary rules governing certification of operators, shall classify the one in charge as well as any of the personnel that might be in charge for any period of time, and shall require operating records; and that no municipality shall hire anyone for responsible charge of a plant not certified.

The rules provide for: the appointment of a Board of Examiners consisting of five members, one representing the Department of Health,

* Presented at the 1939 Annual Meeting of the Michigan Sewage Works Conference, East Lansing.

one representing sewage plant operators, one representing waterworks operators, and two actively engaged in sanitary engineering; the revocation of certificates for incompetency; the issuing of certificates in four classes; and the setting forth of qualifications for applicants for certificates in the various grades. The "Grandfathers Clause" was limited to the extent that those in responsible charge of plants would be given a certificate of the grade his qualifications entitled him to have. The rules really laid down minimum requirements. For instance, a Class A certificate requires that the applicant, besides being a registered engineer, have at least six years experience in the operation of a plant with allowance of two years for college education.

In Illinois, regulations for the issuance of certificates are being adopted. Under these regulations it will not be compulsory that sewage treatment plant operators hold certificates; it will be optional and the purpose will be only to indicate the competency of an operator.

The rules under these proposed regulations provide that: one of three classes of certificates be issued to operators depending on the qualifications of the applicant. The qualifications are based on education, experience, and service rating. The service rating refers to knowledge of plant maintenance, of operation control, and of technique and interpretation of laboratory tests, as well as ability to keep operation records and professional activity. Qualifications of applicants for each of the three grades are briefly as follows:

	Class I	Class II	Class III
Education	College	High School	Grade School
Experience	Six Years	Three Years	One Year
Service Rating	90 Points	60 Points	30 Points

This is a brief and incomplete picture of certification or licensing in other states. Let us now turn to our own state and start with a brief history of our certification.

At our sewage works conference in 1933, a motion was passed authorizing the president to appoint a committee to draft rules and regulations making it necessary for each operator of a sewage treatment plant to be certified by the State Department of Health. This proposal came from the operators, not the Department of Health, and we asked that the Department come to our aid and protect us from the petty municipal politics that had made some operators uneasy. From this point on, the Department cooperated to the fullest extent with the operators. We should remember also that the Department exists for the protection of public health and its regulatory power is therefore limited to the extent of this protection, in general, to the public health of the state.

Your president appointed a committee consisting of Ed Eldridge, Pierre Welch, and W. F. Shephard. This committee drafted tentative rules and then a larger group of operators got together and tore them to pieces. By the time the conference came around in 1934 these rules

were fairly well organised and were presented to the association, where so much discussion was induced that it was decided to get a group of motion was carried after a motion to let the Department of Health draft operators together at a later date to amend the rules further. This last the rules was tabled. Later that summer the operators of all the major plants gathered in Colonel Rich's office and thrashed out rules and regulations.

Some of the high lights of this meeting might be of interest. The proceedings included a decided trend to raise the standards of sewage plant operators by setting the education and experience requirements higher, arguments for certification of every employee of each plant, arguments for the issuing of certificates to all those qualified without examination whether or not they were in responsible charge of a plant, etc. When finally an agreement was reached, the Colonel gave his stamp of approval and the Commissioner of Health was summoned. He gave his approval after asking this one question: "Gentlemen, are you all satisfied with these regulations?" They were then made, what we all considered, law by their adoption by the Advisory Council of the State Department of Health.

You are no doubt familiar with the certification regulations which we operators formulated and which the Department of Health agreed to enforce. The regulations required that all plants be in charge of certified operators, that the Commissioner make rules relative to examining, classifying, and certifying operators, and that certain tests be made and records kept.

The rules provided that the Commissioner of Health appoint an Examining Board consisting of three members, one active sewage plant operator, one member of the Bureau of Engineering, and one at the discretion of the Commissioner; examinations were to be given by this board and recommendations made as to the issuing of or non-issuing of certificates. There were to be three classes of certificates: Classes A, B, and C with minimum qualifications of: high school education and six years of experience (college education to count as four) for Class A, high school education and two years of experience or college and six months for Class B, and grade school education and one year of experience for Class C. These rules by comparison with those of other states are, if anything, a little more lenient. They were effective from 1934 to 1938.

The members of the first Board of Examiners were: E. C. Miller, J. R. Rumsey, and W. F. Shephard. The classification of every plant in the state was no mean task but these men gave freely of their time and deserve to be complimented on the job well done. Those in responsible charge of plants were then given certificates conforming to the classification of their plant. In so doing the State of Michigan had launched a most forward movement for the improvement of sewage plant operation.

How did these regulations work in practice? In general, good. It might be well to state here that these regulations were not perfect, and they were not administered perfectly, but what new project has been

started in which mistakes have not been made? One thing is true, the administrators of the regulations did their best to administer them fairly.

In the old plants, of course, all those in charge at the time the regulations were passed were given certificates. This was fine for all those in responsible charge but here one mistake was made by issuing licenses to a few who were qualified but not in responsible charge of a plant. In doing this some animosities were aroused that did our cause no good. If certification is started again, a strict rule should be made against giving certificates without examinations to more than one individual in each plant.

As new plants were constructed our certification regulations asserted themselves to the benefit of all interested. They prevented placing of some street sweeper in charge of plants of any size, as was previously generally done. In the larger plants certified men were hired and the plants were started properly with less grief to the city fathers, with a decided benefit to the designers (contrary to the opinion of some) with less headaches to the Department of Health, to the economy of the tax payer, and to the advantage and opportunity of the experienced operator.

Difficulty was first experienced in the smaller towns, towns that of course wished to employ local talent and really were not financially able to entice an experienced man into town. There doesn't seem to be much hope for effective regulations in very small towns, but as the size of the town increases the more need there is for regulation of personnel. One effective method found was to place a small town plant under the supervision of a certified operator in some nearby town. In this way a local man could be trained and, at the same time, obtain experience necessary for his certification and again all interested benefited.

The writer's opinion of the factors that had the greatest influence in jeopardizing these regulations follows:

1. In the first place, local politics in an instance or two became clever enough to defy the regulations.
2. There were too few individuals holding Class A certificates that were available.
3. The fact that when certified operators left the older plants there remained an organization that individually or collectively was able to operate that plant, but none in the organization whose knowledge was broad enough to pass the Class A exams that were given.

To get the picture straight, consider that an operator holding a Class A certificate was, under our regulations, entitled to operate any plant in the State of Michigan. Examinations had to be given with this in mind. Possibly here was a mistake in our rules but there seemed to be no other way with only the three classifications.

After so long a time, a showdown had to come. The Board of Examiners met with the Commissioner of Health and it was decided to ask

again for an opinion from the Attorney General as to the legality of our regulations. His opinion was disappointing but sound. It was, in plain language, that any regulation of personnel must come though specific delegation of power from the Legislature and Act 98 of the Public Acts of 1913 did not definitely give such specific power to the Department of Health to regulate personnel, although power was given to regulate the operation of plants. Opinions had been previously received from the Attorney General which were not definite but which implied our regulations were legal. This opinion really put us right back where we started. There was only one thing left to do and that was get legislation through our State Legislature. In the meantime certification was at a standstill.

Shortly after this it was decided to hold a few summer group meetings and the first one was held in Ann Arbor. The president was given authority by those present to appoint a committee to start consideration of a resolution to be presented to the Legislature when it should convene the first of the year. This committee was appointed and a meeting called in Muskegon. Those present were unanimously in favor of getting legislation passed. At this meeting the waterworks association was asked to join with us, for, although the Attorney General's opinion was given for sewage operators certification regulations alone, it presumably would have applied just as much to water plant regulations. The waterworks association appointed a committee that met with the sewage works committee in Jackson. The ground work was here laid for this necessary proposed legislation.

The next meeting of these joint committees was held in Lansing and Mr. Wallace from the Detroit Water Department was made general chairman. Sub-committees were appointed and the campaign details laid down. It was decided to propose an amendment to Act 98 of the Public Acts of 1913 to include authority for the classification of plants, and the examination and certification of operators.

The campaign plans were extensive and minor changes were made at the several following joint committee meetings. The presidents of the different associations wrote letters to each of the senators, and representatives, personal calls were made on several of these legislators and finally each operator was asked to write to the legislators from his district.

Senator Hammond consented to introduce the bill formulated by the joint committee and it was designated as Senate Bill No. 88 and referred to the Senate Health Committee. A hearing was called March 14 at which time our case was presented and it was reported out of committee favorably.

That is the story of our certification. The cooperation given by the fellows in the waterworks association should be appreciated. They certainly were an aid in drafting and carrying this bill No. 88 to the Legislature. My time on this paper will have been well spent if thought has been conceived and pregnant suggestions are forthcoming to the De-

partment of Health to better enable the drafting of rules as fair and as effective as are humanly possible, when and if the Legislature grants the power. In the meantime, put the pressure on your legislators.

SAFETY MEASURES FOR SEWERS AND SEWAGE TREATMENT PLANTS*

JOINT COMMITTEES OF THE NEW ENGLAND AND NEW YORK SEWAGE WORKS ASSOCIATIONS FOR THE PREPARATION OF A SAFETY CODE RELATING TO HAZARDS IN SEWERS AND SEWAGE TREATMENT PLANTS

New Eng. Sew. Wks. Assn. Committee, J. W. Bugbee, R. S. Lanphear and E. Sherman Chase, Chairman

New York State Sew. Wks. Assn. Committee, L. H. Enslow, L. L. Luther and J. L. Barron, Chairman

A. *Safety features in the design of sewers and sewage treatment plants.* (Designing engineers have the responsibility of incorporating safety features into sewers and plants as built.)

1. Prevention of physical injuries by:
   - *a.* Proper design, location and spacing of manhole steps. Provision of guard rails around tanks, stairwells and other openings, and of non-skid stair treads and convenient hand holds.
   - *b.* Placing of guards around moving parts of machinery, gears, belts, etc., and provision of adequate floor space about such machinery.
   - *c.* Effective insulation and grounding of electrical equipment and use of equipment meeting specifications of Fire Underwriters Laboratories.
   - *d.* Construction of fireproof buildings with multiple exits.
   - *e.* The elimination of labor operations that require frequent excessive physical exertion.
   - *f.* Provision of adequate lighting of buildings and grounds.
2. Prevention of infections by:
   - *a.* Provision at sewage treatment plants and at shift operated stations of suitable and convenient toilet and washing facilities.
   - *b.* Avoidance of cross-connections and the installation of an all bronze F–M double check valve on water main leading to sewage treatment plant.
   - *c.* Separation of water and sewer mains and lines.

* *Editor's Note.*—This report has been prepared in outline form in order to present more definitely the salient points directly to the attention of the reader, thereby facilitating its use in its condensed form.

3. Prevention of dangers arising from gases and fumes by:
   a. Standard design of sewers to secure self-cleansing velocities, proper alignment, convenient spacing of manholes, and adequate provision for ventilation.
   b. Engineering recommendation to eliminate main house traps in connection with the proper use of a sewer system.
   c. Engineering recommendation to require adequate oil and grease traps on drains from garages and other establishments using oils or volatile fluids.
   d. Separation of gas and sewer lines in streets.
   e. Segregation and provision for ventilation of enclosures receiving sewage such as grit, screening, and pumping rooms.
   f. Use of non-sparking electrical equipment in enclosures where gases and fumes may occur.
   g. Flame checks, pressure relief devices, and water seals on digestion tank gas lines with all vents to out-of-doors.
   h. Provision against trapping of moisture in gas lines and protection against formation of frost rings by means of pipe of large diameter or by insulation.
   i. Proper location of waste gas burners and engine exhaust discharges.
   j. Placing of chlorine equipment and containers in separate rooms with ample ventilation to outside air. Provision of suitable and adequate equipment for handling chlorine containers.

B. Protective measures to be followed in the operation of sewers and sewage treatment plants. (The official in charge of a sewer system or treatment plant has the duty to eliminate hazards and to develop and maintain safety features.)

1. Prevention of physical injuries by:
   a. Constant safety training of employees and emphasis upon being careful at all times.
   b. Employment of well and physically sound personnel.
   c. First aid instruction to plant operators and foremen and maintenance of first aid kits.
   d. Provision of fire extinguishers and establishment of rules against smoking where explosion hazards exist.
   e. Provision of safety ropes and belts.
   f. Posting of warning signs at points of unavoidable hazards.
   g. Use of adequate personnel on hazardous work.

2. Prevention of infections by:

   a. Routine maintenance of supply of soap and towels and of washing facilities in usable condition at treatment plants.

   b. Education of employees in the need of cleanliness, the use of antiseptics, and the washing of hands before eating.

   c. Inoculation of employees with antityphoid and antiparatyphoid vaccine.

   d. Prevention of cross-connections for priming pumps, for flushing sewage or sludge pipes, care in use of hose for flushing, and breaking of any temporary connections for such purposes immediately after use. Use of distinguishing color on water piping.

3. Prevention of dangers arising from gases and fumes by:

   a. Sponsoring of effective ordinances dealing with discharges of oil, grease, and other chemical or noxious wastes.

   b. Elimination where practicable of main house traps.

   c. Working of men in pairs or with an extra man as lookout.

   d. Ventilation of sewers before entering and use of portable blowers, safety lamps, gas detectors, and masks, as necessary. Toxic gases that may occur in sewers and sewage treatment plants have been tabulated in *Public Works*, volume 69, pages 20–22, for August, 1938, and in volume 69, pages 21–22, for October, 1938, by L. W. Van Kleeck.

   e. Prevention of smoking in sewers, in vicinity of possible gas leaks, or in certain structures at treatment plants. Avoidance of sparks from use of tools.

   f. Alertness to discover gas or gasoline leaks into sewers and prompt location and elimination of them.

   g. Handling of chlorine containers in accordance with manufacturer's instructions, maintenance of tight connections, and of chlorinating apparatus in normal operating condition. Provision of chlorine canister-type mask.

4. General measures:

   a. Posting of general instructions relating to safety procedures and particular instructions and warnings for special features or hazards.

b. Posting of telephone numbers of physicians, police and fire headquarters and of supervising officials at treatment plants and in notebooks of foremen of sewer crews.

c. Teaching of resuscitation methods.

d. Maintenance of safety equipment in working condition.

e. Conformance to provisions of workmen's compensation laws, and posting of required notice to employees.

C. Safety Code.

ALERT TODAY — ALIVE TOMORROW

1. The ABC of safety: Always Be Careful. Do not use intoxicants.
2. Do not light a match or smoke in sewers or sewage enclosures. Use only non-sparking explosion proof safety electric lights.
3. Use a safety belt when entering deep or large sewers or sewage filled pits and have one or preferably two men stand by.
4. Thoroughly ventilate sewers and sewer enclosures before entering. Use a non-sparking, portable blower when necessary. Wear a gas hose mask or self-contained oxygen breathing apparatus if in doubt. Learn in advance how to use such masks.
5. Guard against live wires, slippery surfaces, open manholes, manhole covers, moving machinery.
6. Keep walks free from oil and grease and cover icy walks with sand or salt.
7. Do not permit temporary water flushing pipes or hose to remain connected with sewage or sludge pipes or tanks after use.
8. Insist on: (1) washing and sanitary facilities, (2) protection against hazards, (3) gas masks and other safety equipment.
9. Clean, and use antiseptic on every skin abrasion and wash hands thoroughly, using soap, before handling food.
10. Handle chlorine cylinders with care and don't drop. Follow tag instructions, don't tamper with valve or apply flame, steam, or hot water. Don't place cylinders near steam pipes or radiators. Open valve slowly and leave special wrench in place. Close valve when cylinder is empty. Keep chlorine gas masks ready and accessible, and know how to use them in emergency.

RELATIVE STABILITY CLEANED AND PRESSED *

By John W. Kirkpatrick

Asst. Engineer, Indiana State Board of Health

"Not all them guys ain't got no Standard Method Book," barked the editor in a recent rage. Before him was a monthly report of treatment plant operation . . . his body trembled . . . his voice broke. . . . "Look, Look," he muttered feebly as his shaking finger pointed to a column of relative stability figures. The inquiring reporter obligingly removed the offending report and allowed the delirious body to sprawl on the desk. An incoherent muttering that sounded something like, "Gallopin' catfish, gallopin' catfish," was audible, even after the door was quietly closed and securely locked from the outside.

Lots of the fellows regularly report on the relative stability of sewage plant effluents, but for the benefit of those of us who have been hibernating, let's read a few words from Standard Methods and see what comments are in order.

XIII. Relative Stability of Effluents

Relative stability may be defined as the per cent ratio of oxygen available as dissolved, nitrite and nitrate oxygen to the total oxygen required to satisfy the biochemical oxygen demand, Part III, Sec. XII. This percentage or ratio may be approximately indicated by determining the number of days required to exhaust the available oxygen in the sample, using methylene blue as an indicator.

The use of this determination is rapidly decreasing, as it is being replaced by the more exact determinations of dissolved oxygen, nitrite, nitrate and biochemical oxygen demand. However, for small plants with limited laboratory facilities the stability toward methylene blue fulfills a very useful service in indicating the satisfactory operation of the biological oxidation process. *Standard Methods of Water Analysis*, eighth edition, 1936, p. 159.

Effluents which contain caustic alkalinity or acidity should be neutralized to brom thymol blue and seeded with sewage bacteria before adding the indicator. If bactericidal substances are present that cannot be removed, the method is inapplicable.

The theoretical relation between the time required for decolorization of methylene blue at 20° C. and the relative stability percentage is given in Table 16 and is represented by the relation $S = 100\ (1\text{–}0.794^t)$ in which "S" is the stability in per cent and "t" is the time in days required for decolorization at 20° C.

Reagent

Methylene Blue.—Dissolve 0.5 g. of U.S.P. methylene blue in distilled water and make up to 1 liter.

Procedure

Fill a 150 ml. glass stoppered bottle with sample, *avoiding aeration.* Add exactly 0.4 ml. of methylene blue indicator solution *below* the surface of the liquid. Incubate at 20° C. with a water seal, observing the samples *daily* until decolorization takes place. Report the *days* required for decolorization, or, if preferred, the *relative stability percentage*

* From "The Digester," Vol. III, March, 1940. Edited by P. J. Kleiser, Asst. Engr., Indiana State Board of Health.

shown in Table 16. If other sized incubation bottles are used, a proportional amount of the indicator solution must be used.

TABLE 16.—*Relative Stability Numbers*

Time Required for Decolorization at 20° C. (*t*)	Relative Stability (*S*)
0.5	11
1.0	21
1.5	30
2.0	37
2.5	44
3.0	50
4.0	60
5.0	68
6.0	75
7.0	80
8.0	84
9.0	87
10.0	90
11.0	92
12.0	94
13.0	95
14.0	96
16.0	97
18.0	98
20.0	99

Several observations concerning the relative stability test are in order judging from the results which are submitted each month. In the first place, it is apparent that if a 20 day relative stability is properly reported, it is necessary that the test be continued over a period of 20 days. It follows, then, that if a 20 day stability is reported on the last day of the month, the report of such a finding cannot possibly be obtained before the 20th day of the following month. On several occasions, reports indicating a high stability for a full month have been submitted on the first day of the month following. We can only conclude, in these cases, that the operator did not truthfully report his findings, *or* else that all his findings were "found" some Sunday evening on the dining room table.

The editor said that Confucius said, "If you can't tell the truth, at least make your stories reasonable."

By reference to the relative stability table given on the preceding page, it is apparent that there is no sense in carrying on the test for a period of greater than 20 days. In fact, it is debatable as to whether or not there is any sense in continuing it longer than 10 or 12 days. There have been, however, occasions when relative stability results of 30 or 40 or even 60 days have been reported. Again we can only conclude that the reporter did not have a complete understanding of what he was doing, if he did anything at all.

In other words, if you can prevaricate and get away with it, we have no objections whatever, but if you're not good at deception, it is better to read up on your Standard Methods and do things in a manner similar to the prescribed procedure.

The only requirement in the standard procedure which is beyond the means of a lot of operators is the 20° C. temperature standard. Don't let this worry you. Set the bottles up at room temperature, or in the basement, your results will not suffer too much.

It's probably true that the result of a single relative stability test (or of a small number of tests) is not worth a dime to anyone who operates a sewage treatment plant. However, a well kept continuous record can surely be worth the time and trouble that it takes to amass it. By observation and the exercise of a little feminine intuition almost any treatment plant operator can tell if his plant is in first class operating condition and he can tell if the plant effluent is being assimilated satisfactorily by the stream or ditch into which it is discharged. Records kept during these periods will indicate what particular combinations of relative stability, settleable solids, sewage flow, stream flow, weather conditions and other variables may be expected for that one plant under a given set of conditions.

If at other times, the plant happens to be functioning in a less satisfactory manner, due to increased sewage flow, poor operation, or other causes, the chances are, nine times out of ten that the lower quality of the effluent will make itself known by changes in relative stability or settleable solids before the effect on the stream can be noticed. That is the reason that plant tests should be run religiously every day. An abnormal increase in settleable solids can be determined at once, and, if the effluent is becoming particularly putrid, the chances are that the stability will be about three or four days or even less—soon enough, anyway, to warn that sludge needs to be drawn or that the plant is in a general state of neglect or that there is trouble some place that ought to be investigated.

All this started about relative stability and was instigated by the observation that this item is being determined and reported, in many cases in a very inadequate manner. It all boils down, however, to the fact (as lots of sewage discussions do) that the relative stability test of effluents is truly a relative determination, and, by itself, is a small and useless item. It is valuable as an item of record because it can be correlated with other long time observations to give the sewage plant operator a clue to what is happening and what may happen.

It is apparent, then, that if records are to be used for anything, they have to be accurate and they have to be true. Our respect goes out to the fellow who runs plant tests with the full realization that he may have to refer to them only once in a long time—and our heart goes out to the poor fellow who runs plants tests (or at least records the results of plant tests) with the full realization that his only incentive is state rules and regulations.

REPORT ON THE OPERATION AND MAINTENANCE OF THE DIVISION OF SEWAGE DISPOSAL, DEPARTMENT OF PUBLIC UTILITIES, CLEVELAND, OHIO, FOR THE YEAR 1939

By J. W. Ellms

Commissioner of Sewage Disposal

March 23, 1940

Mr. John A. Hickey,
Director of Public Utilities.
Dear Mr. Hickey:

I am submitting with this letter a condensed report on the management, operation and maintenance of the Division of Sewage Disposal for the year 1939. This report is not the fully detailed report which we anticipate getting out later, but was compiled at the request of the Mayor's office for a summarized report which may be condensed still further, if necessary, for the annual report of the Mayor.

Yours very truly,

J. W. Ellms,
Commissioner of Sewage Disposal

The following report is a summary of some of the salient features of the operation of the Division of Sewage Disposal, Department of Public Utilities, for the year 1939. During the next few months, it is hoped to be able to compile a report embodying the technical details of the operation of the sewage disposal plants, together with information bearing upon the financial status of the Division.

The activities of the Division were chiefly centered on perfecting plant operation by tuning up plant equipment and the regulation of various processes used in the treatment of sewage. The construction work was practically completed during the year, although contractors made numerous changes and adjustments from time to time, as were shown to be necessary in the interest of efficient operation of the plants. Some new equipment was required to suplement existing installations and tests were also required on some of the mechanical equipment before it could be accepted by the City.

Plant Operation

The volume of sewage which passed through the three sewage disposal plants during the year 1939 amounted to 133 million gallons per day. Of this volume of sewage, 60.57 per cent passed through the Easterly Sewage Disposal Plant, 22.73 per cent through the Westerly plant and 16.7 per cent through the Southerly plant. This does not include storm water, which was discharged through overflows at the plants. It also does not represent the overflows at the sanitary diversions on the interceptors, which discharge directly into either the lake or the Cuyahoga River.

The purpose of sewage treatment may be concisely stated to be the removal of solid organic and inorganic matter from the large amount

of water in which it is suspended. The coarsely suspended matter consisted of 1,658 cu. yd. of screenings and 7,608 cu. yd. of grit. The finely suspended matter, which is removed in the more refined treatment processes following the removal of grit and screenings, amounted to practically one ton for every million gallons treated at the Easterly and Southerly plants, and about one-half ton per million gallons at the Westerly plant. The total suspended matter removed at the three plants was approximately 124 tons per day, calculated on a dry basis.

It should be borne in mind that the suspended matter separated at the Easterly activated sludge plant is pumped to the Southerly plant for processing and final disposal. The Southerly plant, in addition, handled approximately 22.2 m.g.d., while the Easterly plant treated 80.6 m.g.d. The Southerly plant therefore processed the suspended matter from approximately 100 m.g.d., although the flow through the plant was only about one-fifth of that volume. Treatment at the Easterly plant is by the activated sludge process, at the Southerly plant by aeration and trickling filters. The sludge is digested in heated tanks. The Westerly plant includes Imhoff tanks plus separate digestion tanks and incinerators.

A few of the details of the effect of the treatment used at the three plants may be briefly outlined as follows:

Easterly Plant.—The reduction in suspended solids affected at this plant was 96.4 per cent. The reduction in the B.O.D., which may be considered as a measure of the destruction of organic matter, was 93.5 per cent. The reduction of bacteria amounted to 99.3 per cent, and during the period when chlorine was applied to the effluent from the plant, this reduction was increased to 99.9 per cent. The percentage reduction in organic nitrogen was 84.1 per cent.

In the activated sludge process, air is blown through the sewage for a period of 5 or 6 hours as it passes through aeration tanks. The volume of air applied per gallon of sewage was 1.16 cubic feet. The sewage, after passing through the aeration tanks, flows into settling tanks. The effluent from these tanks flows directly into the lake. The power required for aerating this sewage, together with other power required at the plant, amounted to 45,795 kilowatt hours per day.

Westerly Plant.—At this plant, 40.5 per cent of the suspended solids settled out in Imhoff tanks. The volume of sludge produced as the result of this settling, was 17,404,700 gallons, which was pumped into six separate digestion tanks. This volume of sludge is somewhat reduced as it undergoes digestion, and during this period, produced 58,078,500 cu. ft. of inflammable gas. This gas is used for incinerating the digested sludge drawn from the digestion tanks and for heating the buildings during the winter months. Of the total gas produced, only 57.2 per cent was utilized at the plant.

The digested sludge, containing about 65.6 per cent of moisture, is vacuum filtered after being conditioned with lime and ferric chloride. There were 317 tons of lime and 84.8 tons of ferric chloride used for the preparation of this sludge for filtration. The lime averaged 11.8

per cent of the dry solids in the sludge, and the ferric chloride, 3.62 per cent.

The filtered sludge cake amounted to 8,545.3 tons. There were used only 1,582 gallons of fuel oil during the period when the incinerators were in use. The average volume of gas used per ton of sludge cake for incineration was 769 cu. ft.

Southerly Plant.—The activities of this plant consist of those processes used on the raw sewage entering the plant and passing through the Imhoff tanks, trickling filters and magnetite filters, and the processing of the sludge pumped from the Easterly plant to the Southerly plant. There is some equipment which was provided for abbreviated aeration and clarification of the effluent from these tanks which dealt with a portion of the effluent from the Imhoff tanks, together with supernatant liquors from concentration tanks and separate digestion tanks.

The average percentage reduction of suspended solids by settlement in the Imhoff tanks was 37 per cent. Further treatment in the trickling and magnetite filters produced an over-all reduction of approximately 85 per cent. The reduction in the amount of iron, of which there is a large amount entering the plant as industrial waste and which seriously interferes with some of our processes, was 82 per cent. The reduction, as measured by B.O.D. was 85 per cent.

The sludge from the Imhoff tanks is partially dewatered on covered sand drying beds. The sludge pumped from the Easterly plant enters concentration tanks, and from there, passes to twelve large separate digestion tanks. During digestion, 268 million cu. ft. of inflammable gas were produced, of which 49 per cent was utilized in the plant.

The digested sludge was conditioned by using 1,616 tons of lime and 414 tons of ferric chloride. The sludge cake amounted to 42,246 tons of wet sludge, and contains 72.4 per cent of moisture on an average. There were used for incineration 237,530 gallons of fuel oil, or approximately 6.1 gallons per ton of filter cake.

Of the total volume of gas produced in the digestion tanks, 42,204,000 cu. ft. was used in the gas engines for compressing air to aerate the Imhoff tank effluent and supernatant liquors in the aeration tanks. This is equivalent to an approximate volume of sixteen cu. ft. per brake horsepower.

Cost of Operation and Maintenance of the Division of Sewage Disposal

On July 17, 1938, the City Council passed an ordinance which provided a sewerage service charge of 40 per cent of the water bill. This produced sufficient revenue for carrying on the activities of the Division, although suburban political subdivisions failed to contribute their proportion of the cost. However, Shaker Heights paid $25,000 on account, instead of making a complete settlement. On October 17, 1939, the City Council passed an ordinance reducing the sewerage service charge to 25 per cent of the water bill and, further, ordered the repeal of any charges for sewerage services, effective January 17, 1940.

The cost of operating and maintaining the plants, together with the administrative costs of the Division, totaled for the year 1939, $978,561.26. This is equivalent to an average monthly outlay of $73,020. It is also equivalent to an average cost of treatment of $20.21 per million gallons.

It has been the effort of the Division to organize and effectively instruct its employees in the duties which they are called upon to perform. More effective results have been obtained as employees gained experience. A very notable improvement along the shore opposite the Easterly Sewage Disposal Plant was noted during the past year, due to the effective processes employed at this plant.

Extensions of the sewerage system in the low level district and at other points in the metropolitan area will increase the volume of sewage to be treated by various plants. The low level district in the Cuyahoga River valley will require an interceptor if the sanitary sewage and trade wastes now flowing into the Cuyahoga River are to receive treatment in the disposal plants.

GREATER WINNIPEG SANITARY DISTRICT

EXCERPTS FROM SUMMARY OF PLANT RECORDS, FOR YEAR ENDED DECEMBER 31, 1939

Commissioners

W. M. Scott, *Chairman*,
H. C. Thompson,
W. P. Brereton,
G. C. MacLean,
185 King Street,
Winnipeg, Canada

Table I.—*Flow and Analysis of Raw Sewage*

Month, 1939	Temp. of Raw Sewage, ° F.	Sewage Flow, M.G.D.	Suspended Solids, P.P.M.	Hydrogen Ion Conc., pH	B.O.D., P.P.M.
January	52°	14.0	268	7.8	388
February	51°	15.5	295	7.7	410
March	50°	14.2	298	7.0	325
April	52°	17.5	315	7.8	370
May	55°	20.1	400	7.8	385
June	59°	21.4	330	7.8	360
July	65°	20.3	300	7.8	330
August	66°	20.5	330	7.7	318
September	64°	18.3	340	7.7	330
October	62°	18.9	480	7.7	500
November	58°	16.9	440	7.6	523
December	56°	21.4	440	7.6	570
Average	57°	18.2	353	7.7	407

TABLE II.—*Results of Operation of Clarifier*

Month, 1939	Settleable Solids, Cc. Per Liter			Suspended Solids, P.P.M.			B.O.D., P.P.M.		
	Inf.	Eff.	Per Cent Rem.	Inf.	Eff.	Per Cent Rem.	Inf.	Eff.	Per Cent Rem.
January	4.2	1.3	69	285	145	49†	388	260	33
February	4.6	1.7	63	295	160	46†	410	260	37
March	4.6	1.5	67	312	174	44†	325	235	28
April	5.0	2.1	58	320	180	43.7†	370	250	32
May	5.5	2.0	63	330	170	47†	385	265	31
June	5.0	1.9	62	340	170	50	360	270	25
July	4.3	1.5	65	310	150	51	330	220	33
August	5.5	1.4	74	415	160	61	318	182	43
September	6.0	1.5	75	340	160	53	330	200	40
October	8.0	3.0	62.5	450	257	43.1	500	370	27.4
November	8.0	2.9	63	456	254	44.3	523	370	29.2
December	8.3	5.4	35*	450	320*	27*	570	465	18.5
AVERAGE	5.7	2.2	63	358	191	46.6	470	279	31.4

* Includes digested solids from Digester No. 3. † Includes scum from Digesters No. 1 and No. 2.

TABLE III.—*Solid Matter Removed from Raw Sewage*

Month, 1939	Grit, Cu. Ft. Per Month	Suspended Solids, Pounds Per Month	
		*Total	Volatile
January	3,170	566,465	382,363
February	2,845	486,636	327,019
March	2,750	559,281	347,872
April	1,550	688,042	432,090
May	2,085	778,412	504,410
June	1,793	906,220	554,606
July	2,580	879,823	540,211
August	3,285	1,123,544	676,373
September	3,195	802,796	500,944
October	3,130	937,613	681,644
Nobember	2,925	868,184	645,928
December	5,155	797,125	605,815
TOTAL	34,463	9,394,141	6,199,275

* Estimated from readings of Venturi Meters and laboratory tests of removal of suspended solids.

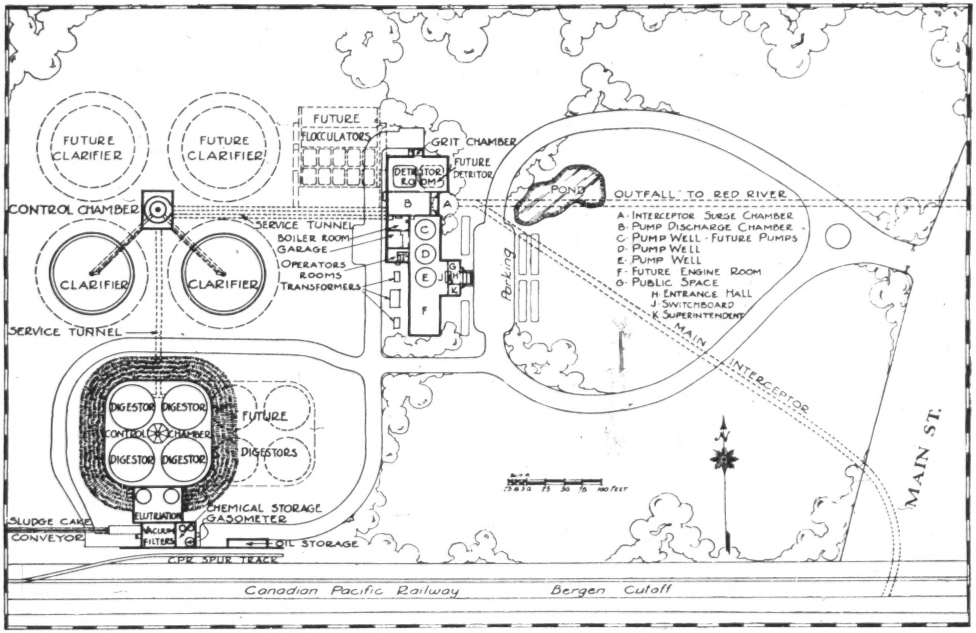
TABLE IV.—*Analyses of Sludge, Averages, Year 1939*

Source	pH	Per Cent Moisture	Per Cent Volatile, Dry Basis
Sludge to Digester No. 1	6.6	91.9	66.7
Sludge Transferred to Digester No. 3	7.6	93.0	52.4
Sludge Withdrawn from Dig. No. 3	7.8	88.9	49.2
Supernatant, Dig. No. 3	7.5	98.1	51.9
Sludge to Digester No. 2	6.8	92.0	66.3
Sludge Transferred to Dig. No. 4	7.6	93.3	53.5
Sludge Withdrawn from Dig. No. 4	7.8	88.8	48.8
Supernatant, Dig. No. 3	7.8	97.7	51.1

Average Temperature	
Digester	Deg. F.
1	92
2	89
3	87
4	88

TABLE V.—*Production and Analysis of Gas*

Month, 1939	Gas Produced		Gas Wasted		Gas Burned in Boilers, Cu. Ft. Total	Analysis	
	Total, Cu. Ft.	Average Per Day, Cu. Ft.	Total, Cu. Ft.	Average Per Day, Cu. Ft.		CO_2	CH_4
January	5,568,900	179,640	2,320,600	74,860	3,248,300	31.6	67.9
February	4,568,900	163,175	1,382,400	49,370	3,186,500	31.9	67.8
March	5,278,900	170,290	2,003,800	64,640	3,275,100	32.2	67.0
April	4,711,300	157,000	2,003,900	91,000	2,707,400	32.3	67.3
May	3,516,900	113,444	1,314,700	42,410	2,202,200	32.2	67.0
June	5,194,400	173,140	2,974,500	99,150	2,219,900	32.0	67.8
July	8,266,800	266,700	5,876,700	189,500	2,390,100	31.8	67.8
August	6,264,400	202,000	3,869,400	124,800	2,395,000	31.4	68.5
September	6,280,600	209,353	4,044,930	134,830	2,235,670	32.0	67.6
October	8,368,600	269,950	5,358,800	172,800	3,009,800	32.1	67.5
November	9,119,500	303,900	5,866,600	195,500	3,252,900	32.3	67.0
December	4,956,100	159,900	1,567,300	92,100	3,388,800	35.6	65.7
TOTAL	72,095,300	2,368,492	38,583,630	1,330,960	33,511,670	387.4	808.9
Aver. per day		197,300		110,900		32.1	67.4



GREATER WINNIPEG SANITARY DISTRICT.—General arrangement of sewage Treatment plant. Showing present installation of 25 million gallons per day and future extensions.

TABLE VI

Month, 1939	Elutriation				Filter Operation							
	Total Sludge, U. S. Gal. (Est.)	Total Wash Water, U. S. Gal. per Month	Elutriated Sludge		Ferric Chloride (Anhydrous)		Per Cent $FeCl_3$ in Cake	Filter Cake				No. of Days Filters in Oper-
			pH	Per Cent H_2O	Total for Month, Lbs.	Average Per Day of Run, Lbs.		Tons Per Month	Per Cent H_2O	pH of Filtrate	Per Cent Vol. Elut. Sludge	
Jan.	580,000	2,083,400	7.5	91.4	11,502	767	2.7	755	72.8	6.6	52.9	15
Feb.	—	—	—	—	—	—	—	—	—	—	—	—
Mch.	325,000	1,260,025	7.5	90.9	4,982	553	2.2	423	71.2	6.8	51.1	9
April	95,000	385,300	7.6	89.7	1,506	753	1.9	137	70.4	6.8	45.9	2
May	435,000	1,416,400	7.6	89.8	4,869	443	1.7	443	68.5	6.8	47.7	12
June	485,000	2,045,600	7.6	88.2	6,961	497	1.5	711	66.1	6.8	45.7	14
July	410,000	2,456,875	7.7	87.9	7,209	515	1.7	631	67.2	6.8	46.5	14
Aug.	527,000	4,267,575	7.7	88.4	11,369	541	2.1	614	68.8	6.8	45.4	21
Sept.	341,000	2,872,400	7.6	87.8	6,652	443	1.9	539	68.1	6.8	43.0	15
Oct.	570,000	3,569,345	7.7	88.2	13,807	575	2.2	989	69.2	6.7	44.3	24
Nov.	760,000	3,947,450	7.7	90.0	13,260	602	2.1	1,105	71.5	6.7	49.5	22
Dec.	327,000	1,784,450	7.6	91.2	5,591	559	2.3	474	74.4	6.7	53.7	10
Avg.	441,300	2,370,000	7.6	89.4	7,970	568	2.0	638	69.8	6.7	47.8	158

Elutriation operating 161 days. Filters operating 158 days.

TABLE VII.—*Operating Costs, 1939*

	Superintendence and Labor	Supplies and Expenses	Maintenance of Bldgs., Fixtures and Grounds	Maintenance of Equipment	Power and Light	Water and Sewer Rental	Auto and Truck Expenses	Printing, Stationery and Statistical Supplies	Taxes and Rentals	Administration General	Workmen's Compensation and Insurance	Total for Month
January	$ 3,834.43	$ 394.13	$ 23.48	$ 148.52	$ 1,867.98	$ 61.68	$ 118.92	$ —	$ —	$ —	$ —	$ 6,449.14
February	3,341.78	455.05	97.12	1,369.94	1,860.68	26.82	115.84	—	—	—	—	7,267.23
March	3,499.60	599.83	.24	21.30	1,712.11	4.18	207.16	—	—	666.28	—	6,710.70
April	4,013.47	360.43	902.84	1,431.65	1,957.90	—	119.88	—	—	475.37	—	9,261.54
May	3,802.84	579.58	262.87	1,161.86	2,055.80	24.01	133.95	—	—	426.04	—	8,446.95
June	3,814.08	229.20	246.19	475.20	2,185.76	542.23	198.50	401.86	—	802.83	1,062.50	9,958.35
July	3,841.17	451.12	375.26	915.87	1,742.63	—	172.60	15.69	774.76	215.36	—	8,504.46
August	4,114.49	324.53	2,377.42	1,511.99	2,102.79	—	134.19	34.93	—	409.29	194.75	11,204.37
September	3,823.84	1,228.13	355.64	1,372.40	2,035.28	25.59	142.17	28.97	75.25	3.59	—	9,090.86
October	3,814.62	1,754.11	714.45	578.16	2,105.30	8.94	211.72	57.25	—	669.46	27.91	9,941.92
November	3,565.42	2,450.49	1,103.93	809.26	2,209.69	—	123.81	83.87	—	223.60	26.77	10,596.84
December	3,550.87	685.44	399.12	1,675.32	2,253.05	108.13	173.97	58.68	1.00	543.93	1,110.02	10,559.53
TOTAL	$45,016.61	$9,512.04	$6,858.56	$11,471.47	$24,088.97	$801.58	$1,852.71	$681.25	$851.01	$4,435.75	$2,421.94	$107,991.89

Editorial

ANNOUNCEMENT

FIRST ANNUAL CONVENTION OF THE FEDERATION IN CONJUNCTION WITH THE THIRTEENTH ANNUAL MEETING OF THE CENTRAL STATES SEWAGE WORKS ASSOCIATION, CHICAGO, ILL., OCTOBER 3, 4 AND 5, 1940

The First Annual Convention of the Federation of Sewage Works Associations will be held in Chicago, October 3, 4 and 5, 1940, at the Sherman Hotel. Plans for this meeting have been under way for some time, following the invitation of the Central States Association to the Federation, at its Annual Meeting last January, to hold its first convention at Chicago. This invitation was considered favorably by the Board of Control and Chairman Emerson appointed a Committee, headed by George Schroepfer of Minneapolis, to canvass the member organizations with reference to this proposal. Questionnaires were sent to the officers of all American and Canadian Associations. The answers were as follows:

HOLD MEETING IN 1940?

	Members Represented	Per Cent of Membership	Number of Associations
Yes	2090	82.6	17
No	30	1.2	1
Indefinite	370	14.6	2
No answer	40	1.6	2
Total	2530	100.0	22

LOCATION OF MEETING PLACE

East	340	13.4	4
Midwest	1495	59.0	9
Indefinite	655	26.0	7
No answer	40	1.6	2
Total	2530	100.0	22

These results indicated an overwhelming vote in favor of a national meeting, and also a decided preference for the Middle West. Chairman Emerson therefore began to work on the selection of a convention city and in an executive meeting held during the Trenton meeting of the New Jersey Sewage Works Association, March 22nd, it was decided that Chicago was the place to hold the convention.

The New Jersey meeting was a great success, under the able leadership of Wm. Orchard. Exhibits, program and finances were very successful. With this meeting as a demonstration, Mr. Orchard urged the Federation to proceed as rapidly as possible with plans for the Fall convention, and offered to help in

all possible ways to put over a successful convention, and to plan for increased activities of the Federation.

The Central States Executive Committee held a meeting in Chicago April 13th and made preliminary plans for the meeting to be held in October. Committee chairman were appointed and hotels were canvassed. The best dates appeared to be October 3rd, 4th and 5th, just prior to the Convention of the American Public Health Association in Detroit.

Meanwhile Mr. Orchard was working hard to enlist the aid of manufacturers of water and sewage works equipment. It was realized that exhibits of equipment and supplies would greatly add to the value of the convention. Mr. Orchard organized the manufacturers at the Kansas City meeting of the American Water Works Association and obtained authority from them to go ahead with the Central States committees, to put over the best line of exhibits ever held at a sewage works convention. The Water Works Manufacturers also put at his disposal a sum of $5,000 to be used as he and his Committee (Messrs. Chevalier, Brush, Kienle and O'Brien) saw fit, to promote the growth of a national sewage works association of increased usefulness and prestige. This sum was not, however, earmarked for the convention.

Mr. Orchard arrived in Chicago May 8th for a meeting with Mr. Schroepfer, Chairman of the Federation Committee, B. A. Poole, President of the Central States Association, and the Chicago Local Arrangements Committee, General Chairman F. W. Mohlman. The dates of the meeting were set, the hotel selected, and many details of the convention discussed.

The Program Committee is under the Chairmanship of C. K. Calvert, of Indianapolis, and they are at work on preparation of the technical program.

The Chicago Committee is ready to go and tentative plans include a smoker, a banquet, a trip to the Southwest Treatment Works of the Sanitary District of Chicago, an operators' breakfast, and ladies' entertainment. The Sherman Hotel will make special rates to be announced later, and Chicago ought to have the best weather of the year early in October.

Chairman Emerson is working hard on plans for the revitalized Federation. Committees are meeting in New York and soon their plans will be submitted to the Federation for consideration. There is no intention of changing the present setup of local associations and meetings in the slightest degree and all of the good features of the present structure will be retained. The help of all members of the Federation is earnestly requested to make a real success of the convention and the strengthened Federation. A large amount of time and effort is being spent by those responsible for the convention and reorganization of the Federation, and they are not doing it for money but for the best interests of the sewage works profession. A similar spirit will undoubtedly motivate all loyal members of the Federation.

F. W. MOHLMAN

Proceedings of Local Associations

SEWAGE DIVISION, TEXAS SECTION, S. W. W. A., TEXAS WATER WORKS AND SEWAGE SHORT SCHOOL

Twenty-second Annual Meeting,

College Station, Texas, February 19–23, 1940

The Texas Water Works and Sewage Short School held their Twenty-second Annual Meeting at College Station, Texas, during the period February 19–23, 1940. Registration showed the attendance of 254 members and guests.

The program was divided into three sections—water, sewage and laboratory. All of the sections were well attended and much interest was manifested in all subjects. Of increasing interest and concern to the entire group is the treatment and disposal of industrial wastes and particularly the salt water waste from oil fields. All phases of this important subject were discussed including the legal aspects of the problem.

The "Gadget Session" which was introduced at last year's school was repeated this year and gained considerable interest and favorable comment although there was a decrease in the number of "gadgets" on display.

On Tuesday evening there was a joint meeting of all district water works and sewage associations in the State. Each of the sixteen district associations were represented at this meeting. This phase of the program is steadily increasing in interest and activity, and, therefore, it was the opinion of the group that the State should be distributed in order to prevent overlapping of boundaries of the various organizations. A committee composed of V. M. Ehlers of Austin, and C. E. Collins of Kilgore, was appointed for this purpose. This group also expressed their gratitude to the State Department of Health and to the State Board of Vocational Education for their assistance in the district program. A discussion with officials of the Vocational Education Department brought out the desirability of devoting at least one-half of the time at the monthly meetings to a planned program including one paper to be given locally probably covering a chapter in the Water Works Operators Manual, fifteen minutes devoted to round-table discussion on some pertinent problem, probably a fifteen minute film and the remainder of the program to be a paper by some special outside speaker on a subject of interest to the entire group.

Wednesday evening the group heard an excellent paper prepared and delivered by W. E. Jameson of Houston, President of the Associated Master Plumbers of Texas.

Following this session a business meeting was held where reports from the various committees were read.

1. E. J. M. Berg, Chairman of the Committee on Certification of Sewage Plant Operators, presented a report setting forth amended qualification requirements for the various grade certificates. The report was accepted as read.

2. C. L. Fugate, Chairman of the Committee on Water and Sewer Rating, presented a report recommending a rating schedule for sewage treatment plants and systems. Since this report was too lengthy to be read aloud at the session and further, since it was the opinion of the majority that it should be studied carefully before adoption, it was voted that the membership accept the offer of R. M. Dixon of Dallas to have copies prepared and distributed among the members and that the report be presented for further discussion at next year's school.

3. W. S. Mahlie, Chairman of the Committee on Certification of Laboratories, read a report setting forth advisory standards for the certification of laboratories including personnel, operation and equipment. The report was accepted as read.

4. D. B. Dickson, Chairman of the Committee on Disposal of Salt Water Waste, reported that this committee's report was in the form of a resolution which was being presented for adoption. The resolution outlined three methods of disposal of the salt water which might be permitted; namely, piping the salt water to the Gulf, returning it by injection wells either to its original stratum or to the stratum below, or at least six months' storage in pits. Clyde R. Harvill of Houston offered a motion for the amendment of the resolution to read "adequate" storage and further that the State Health Department be the enforcing agency and that the chloride content not exceed 250 p.p.m. by laboratory analysis. The motion was accepted and the report was adopted with the aforementioned amendments.

5. Jeff Logan, Chairman of the Auditing Committee, read the report which included a financial station of the organization. The report was accepted and a rising vote of thanks was given to Mrs. Earl H. Goodwin, Treasurer, for her service.

6. J. L. Horner, Chairman of the Committee on Rural Sanitation, presented the report in the form of a resolution offering the assistance of the membership in the form of advice and counsel to the county supervisors of the Farm Security Administration. This assistance will be rendered in connection with the FSA program for the improvement of sanitary facilities at the homes of FSA clients including water supply and sewage disposal. The resolution was adopted as read.

The annual banquet was held on Wednesday evening with the President, Ashley G. Classon, presiding. Dr. George W. Cox, State Health Officer, was the principal speaker and outlined the progress that had been made during the past year in the water works and sewage program in Texas. On behalf of the State Department of Health, Dr. Cox presented trophies as awards to: (1) San Marcos for having maintained the

best sewage effluent during 1939. (2) Huntsville for having made the great improvements in their sewage treatment plant, and (3) Groesbeck for having made the greatest improvements to their water treatment plant. In addition, numerous other cities were given recognition and honorable mention for outstanding achievement.

J. L. Horner, Chairman of the Resolutions Committee, presented their report which was unanimously accepted by the group.

D. B. Dickson, Chairman of the Committee on Awards, presented several awards as follows:

1. A plaque to the Rio Grande Valley Water and Sanitary Association for having the greatest number of members in attendance at the Short School and also having travelled the greatest number of man miles.

2. Honorary life memberships in the organization were presented to V. M. Ehlers of Austin and Lewis A. Quiley of Fort Worth for their many years of active and valuable service.

3. A copy of *Modern Sewage Disposal* was presented to J. N. Hinyard of El Paso for the most unique gadget on display at the School.

4. Honorable mention was given to those cities which had secured during 1939 (*a*) the greatest decrease in insurance key rates, (*b*) approval of the water supply by the State Department of Health, and (*c*) a licensed operator in charge of the water plant.

J. L. Fortson, Chairman of the Nominating Committee, presented the report and the following officers were unanimously elected by acclamation: *President,* D. B. Dickson, Wichita Falls; *First Vice-President,* S. C. Clark, San Benito; *Second Vice-President,* M. J. Salmon, Commerce; *Third Vice-President,* Roy Matthews, Albany; *Fourth Vice-President,* W. F. Hicks, Paris; *Secretary,* V. M. Ehlers, Austin; *Asst. Secretary-Treasurer,* Mrs. Earl H. Goodwin, Austin.

On Friday afternoon, Dr. W. T. Gooch, Chairman of the Licensing Committee, conducted examinations for the Water Supply Operators' Licenses. Twenty-one operators took the examination most of which were for Grade B and Grade A licenses. This session closed one of the most successful Short Schools which has ever been conducted.

(Mrs.) Earle H. Goodwin, *Asst. Secretary*

NEW ENGLAND SEWAGE WORKS ASSOCIATION

Spring Meeting,
Middletown, Connecticut, April 16, 1940

The spring meeting of the New England Sewage Works Association was held on April 16, 1940, at Higgins' Inn and Restaurant, Middletown, Connecticut. One hundred and thirty-six members and guests were registered for the meeting which equalled the previous record for a spring meeting in Greenwich in 1934. In the morning, members and

guests inspected the Middletown sewage treatment plant and refuse incinerator. The Association luncheon was held at 1:00 P.M. Mr. Walter J. Shea, second vice president, presided because of the illness of President A. D. Weston. Mr. F. W. Gilcreas, a member of the committee on reorganization of the Federation, discussed Federation affairs immediately following the luncheon. He outlined the work which has been done to date toward the formation of a stronger Federation.

The secretary and treasurer submitted reports. These reports contained several record-breaking figures. The treasurer reported a balance as of April 2 of $562.94 and a membership as of April 1 of 185. New members since September 15, 1939, numbered 20 and the secretary reported a number of new applications had been received on the day of the meeting. He anticipated that the membership would exceed the 200 mark this year. There was an all time record at an annual fall meeting of 134 at Winchendon, Massachusetts, on September 29–30, 1939. The death of the following members was reported: Christopher Hanson, Stephen deM. Gage, and E. H. Sprague.

The report of the secretary was followed by a question and answer period on the operation of the Middletown sewage plant. Mr. Samuel C. Cannon, Superintendent of the Department of Public Works, followed with a report on records of operation of the Middletown plant.

The first paper of the technical session entitled "Cranston, Rhode Island, Sewer System—A W.P.A. Construction Project" was presented by Mr. R. W. Horne, Resident Engineer for Fay, Spofford and Thorndike, of Boston, Massachusetts. The paper was illustrated with lantern slides.

The second paper of the technical session was given by Mr. L. L. Langford, Eastern Sales Manager of the Pacific Flush-Tank Company, New York City, on "Sewage Gas Utilization Systems." His paper was also illustrated by lantern slides.

Mr. Langford was followed by Professor C. R. Hoover of Wesleyan University, who spoke on the sewage and industrial waste research work at the Hall Laboratory of Chemistry. His talk was followed by a visit to the Laboratory. The Association dinner was held at Higgins' Inn and Restaurant at 6:15 P.M. Professor Edward C. Schneider of Wesleyan University spoke as the after-dinner speaker on "Problems in Sewage Disposal."

Available at the meeting were the Safety Code Placards by the Joint Committees of the New York State Sewage Works Association and the New England Sewage Works Association. These were available on both paper and cardboard.

Chairman Shea announced that the next meeting of the Association would probably be held in Springfield, Massachusetts.

LeRoy W. Van Kleeck, *Secretary*

Reviews and Abstracts

THREE CONTRIBUTIONS ON THE HOWARD PROCESS FOR DISPOSAL OF WASTE SULFITE LIQUOR

I. SULFITE LIQUOR DEVELOPMENTS

By Guy C. Howard

Chemical and Metallurgical Engineering, 46, 618–619 (Oct., 1939)

This paper describes the process developed by the Marathon Paper Mills Company for the disposal and utilization of waste sulfite liquor containing the lignin and hemicellulose constituents of the wood dissolved in the pulping process. The objects of the research work which led to the development of this process were: (1) "to reduce stream pollution (2) to supplement the value of the cellulose pulp by recovering the valuable constituents of the large quantity of non-cellulose organic matter going to waste in such liquor."

The work resulted in the development of the Marathon-Howard Processes and waste sulfite liquor is now being treated on a commercial scale by these methods at a Rothschild, Wisconsin, mill. The result has been "a reduction in stream pollution and the manufacture of a variety of products for use by the pulp mill and for sale."

The main process involves a three-stage lime precipitation treatment. The waste liquor is pumped over an inclined screen to recover fiber and is then collected in raw liquor storage tanks where strong and dilute liquors equalize in concentration. Over 90 per cent of the total organic matter dissolved from the wood is carried by liquor collected. The process does not involve evaporation hence both strong and dilute liquor may be economically handled.

Hot liquor from a storage tank is pumped to first reaction tank in which "a caustic lime reagent" is added. Amount of chemical is varied in order to precipitate an inorganic product which is essentially calcium sulfite. The settled precipitate is pumped as a slurry to pulp mill for use in making fresh cooking acid. The remaining clear liquor flows to second reaction tank where it is treated with the lime reagent for precipitation of an organic product. After the precipitate has settled it is removed as a wet cake on a rotary vacuum filter. The precipitate is essentially a basic calcium salt of lignin sulfonic acid and may be used as a lignin raw material or as a boiler fuel.

The liquor then flows to a third reaction tank where it receives a stripping treatment with an excess of "lime reagent." This precipitates additional lignin material which is settled out together with unconsumed lime reagent and returned as a slurry for use in the process as the "lime reagent" in the first reaction tank. Any clear liquor remaining may be discharged into waterways with materially less polluting effect than would result from raw liquor. This effluent is hot and alkaline with lime. The heat content may be utilized to heat wash waters. Still further processing will yield additional products. (Ref. *Paper Trade Journal*, July 2, 1936.)

B.O.D. reduction has been found to be approximately 80 per cent. (No other figures are given.) Further purification can be accomplished either by yeast fermentation of raw liquor prior to the lime precipitation, by biological treatment in a trickling filter of the effluent from the lime precipitation (pH of effluent not given) or by giving effluent a brief pressure cook to precipitate additional organic matter.

The most fundamental accomplishment of this process is considered to be the segregation of the major components of sulfite liquor which facilitates its more complete utilization and makes available a large tonnage of low cost lignin.

Plant operations have demonstrated the feasibility of the process and have largely confirmed original estimates of yield and cost. Basic lignin sulfonate recovered is com-

parable with coal as to chemical potentialities and when the moisture content is reduced to 50 per cent by filtering and pressing, has been successfully used as boiler fuel with 10 per cent admixture of coal screenings.

One-third of the vanillin used in U. S. is made from this lignin material. Many other products are possible and the magnesium, calcium and sodium salts of lignin sulfonic acid are now being made and sold on a tonnage basis for use in tanning, cement making, boiler water treatment, dispersing agents, grinding aids, etc.

The processes are patented but are available to sulfite industry as a disposal method for sulfite liquor, with the use of recovered products restricted to the making of fresh cooking acid and as a boiler fuel. Due to necessity of balancing production with market outlets, patent rights for the manufacture and sale of special lignin products cannot be made generally available.

PAUL D. HANEY

II. POLLUTION SURVEY AT GREEN BAY, WISCONSIN

By Wisconsin State Committee on Water Pollution and State Board of Health in Collaboration with The Green Bay Metropolitan Sewerage District. Mimeographed Report, 242 pages, 1938–1939.

BY L. F. WARRICK

Chief Engineer, Wisconsin State Dept. of Health

This report presents the results of an extensive pollution survey of the waters of the lower Fox River, the East River, and Green Bay tributary to the northwestern corner of Lake Michigan. It was found in a previous investigation that pollution from domestic sewage was insignificant when compared with that from waste sulfite liquor. This led the board to special studies on the characteristics of waste sulfite liquor and methods for its treatment, particularly the Howard Process in use at the Marathon Paper Mills at Rothschild, Wis. This abstract deals principally with the characteristics of waste sulfite liquor and the Howard Process.

The Howard Process involves three-stage lime precipitation of the liquor, each stage being comprised of a chemical feeder, reaction tank, and clarifier. In the first unit the pH of the liquor is raised to 11.5 to precipitate calcium monosulfite. This is reused to make fresh acid for the sulfite cooking liquor. A recovery of 70 to 80 pounds of sulfur per ton of air-dried pulp, is obtained. More lime is added in the second stage to raise the pH to 12.5 or 13.0. The resulting sludge contains 13 to 16 per cent CaO and the remainder is mostly lignin. This material can be filtered and burned, or used for the recovery of by-products such as vanillin, plastics, and tannery agents. In the third stage an excess of lime is added to remove as much lignin as possible. The sludge contains mostly $Ca(OH)_2$ and is returned to the first reaction tank to affect a saving of chemicals. In this survey a study was made of the effluent from the Howard Process, including reductions in B.O.D. and volatile solids and the amount of hydrogen sulfide which could be generated under the anaerobic conditions existing in the East River at Green Bay.

The results indicated that the process will bring about a 43.5 per cent reduction in the amount of hydrogen sulfide produced. The waste sulfite liquor will generate 30 p.p.m. of H_2S in eight days whereas the Howard effluent produces an ultimate of 17 p.p.m. in the same time. However, concentrations as low as 4 to 5 p.p.m. of H_2S in the East River are causing an odor nuisance. A special procedure was developed for this determination. It depended upon the change of color of a lead acetate treated paper by the formation of lead sulfide. Air was bubbled through the sample to force out the H_2S which in turn was passed through filter paper to react with the acetate. The resulting color was compared with that from known standard concentrations of H_2S in a liquid.

Before making studies of the oxygen consuming materials in the waste sulfite liquor it was necessary to determine the proper dilution water which would give data indicative of conditions to be expected in the East River. Studies were made on dilution

waters and their effect on the rate of oxygen demand and ultimate B.O.D. of the liquor. Unseeded bicarbonate water made up according to "Standard Methods" was first used. Then a fortified water was made containing sodium bicarbonate and other minerals found in natural waters, as well as bacterial life for seeding. The third water used was that obtained from an unpolluted section of the East River and aged for two weeks. Tests on waste sulfite liquor showed a 20° C. 5-day B.O.D. of 750 p.p.m. and a 60-day B.O.D. of 7,000 p.p.m., using standard water. The fortified water gave values of 11,500 and 27,000 p.p.m., respectively, while the East River water gave 11,500 and 27,500 p.p.m. for the 5-day and 60-day B.O.D. results. Similar behavior was noted on the determinations of B.O.D. at 0° C. It was concluded that for consistent results it would be desirable to use East River water as the dilution medium after aging.

The separate woods and types of cooking used produce waste sulfite liquors of different characteristics which affect the results of lime precipitation. Hemlock yields a greater amount of lignin than spruce. The more intense the cooking, the greater the dissolution of carbohydrates. Therefore, in the tests it was necessary to take samples from each mill representative of the combinations of poplar, spruce, and hemlock used, and the type of cooking. Each of the samples obtained from the mills was subjected to lime precipitation in the laboratory to predict the B.O.D. removals to be expected through the use of the Howard Process at each of the mills. The reduction in B.O.D. is greatest with hemlock because this wood yields the highest amount of lignin. In general the reduction is lowest for the hardwoods on account of the higher percentage of carbohydrates present in the waste liquor from these woods. Tests on nearly pure calcium ligno sulfite show that by itself it has very little B.O.D. The explanation for this is based on the fact that the lignin compound occurring in waste sulfite liquor is mostly calcium ligno sulfite in a colloidal state. This cannot be attacked by bacteria until broken down by enzyme action. Using the nearly pure compound only, there was no chance for enzyme production, and consequently no biochemical oxidation of the lignin. On the other hand, tests on carbohydrates show that the pure compounds are easily broken down by bacterial action. With waste sulfite liquor present, sufficient carbohydrates were furnished for bacterial food and enzyme production, permitting the colloidal lignin to be broken down and oxidized. Lignin probably exerts an appreciable oxygen demand as long as carbohydrates are present. After the utilization and disappearance of the latter, the remaining liquor would have a very small oxygen demand, similar to the behavior of pure calcium ligno sulfite. Carbohydrates are mostly in solution and are not susceptible to chemical precipitation. They require some form of biological treatment for removal.

Tables are presented to show that the 20° C. 5-day B.O.D. contributed to the Fox River by the mills above DePere at various flows and the reduction in B.O.D. which might be expected at these flows by treatment of the waste by the Howard Process. These values are added to those from other sources to get the total B.O.D. of the Fox River. These computations show that at flows of 1,000 c.f.s. or less the reduced B.O.D. would be 19 p.p.m., of which 17.4 p.p.m. would still be provided by the waste sulfite liquor after lime precipitation. At 2,000 c.f.s. the reduced B.O.D. would be 8.9 p.p.m., of which 8.1 p.p.m. would be contributed by the treated liquor. Therefore, it would appear that treatment of waste sulfite liquor by the Howard Process alone would not prevent critical conditions in the lower Fox River at periods of low flow and high temperatures.

The conclusions drawn from these experiments are as follows: (1) The dilution water used has a great effect upon the B.O.D. values obtained, and in order to predict future oxygen demand conditions in a body of water, its water should be aged and used for dilution water. (2) Fortified dilution water closely approximates the river waters used for dilution water in this survey. (3) Standard sodium bicarbonate dilution water is of no value in determining the B.O.D. of waste sulfite liquor in relation to oxygen depletion in any given surface water. (4) The characteristics of the B.O.D. curves of waste sulfite liquor at 0° C. and 20° C. are markedly different. At 0° a lag is observable, while none exists at 20°, and at 0° the rate of oxidation and the ultimate demand for a given period are considerably less than at 20° C. (5) The free sulfur dioxide contained

in waste sulfite liquor contributes a very negligible amount of B.O.D. to the total B.O.D. This reaction proceeds biochemically and requires 5 days or longer for practically complete oxidation. (6) The lignin contained in waste sulfite liquor may or may not exert a high oxygen demand depending apparently upon the presence or absence of carbohydrates. (7) The greatest percentage of the oxygen demand is caused by the carbohydrates contained in the waste sulfite liquor. (8) Even though treatment of this liquor by lime precipitation removes 70 to 80 pounds of sulfur for each ton of air-dried pulp produced, there still remains enough sulfur combined with lignin to produce hydrogen sulfide in sufficient quantities to cause an odor nuisance under anaerobic conditions and in the presence of carbohydrates. (9) From these studies, various dilution waters were found to have the same effect on B.O.D. values of waste sulfite liquor after lime precipitation treatment that they have on the untreated waste liquor. (10) Waste sulfite liquor after lime precipitation produces the same type of B.O.D. curve at 0° C. and 20° C. as the untreated liquor, the two curves differing only in their ultimate value for any elapsed period. (11) The percentage reduction in the 20° C. B.O.D. as obtained by treating waste sulfite liquor by the Howard Process will vary over a wide range, depending upon the type of wood and the method of cooking employed. The tests indicate that a minimum value of 31 per cent and a maximum of 45 per cent may be obtained. The reduction of volatile solids is within the same range. The above reductions are affected mainly by the removal of free sulfur dioxide and lignin. Very few, if any, carbohydrates are removed. (12) The installation of equipment for treatment of waste sulfite liquor by the Howard Process, or some other means of lime precipitation, in the mills along the lower Fox River will not prevent the development of critical conditions in the Fox River at periods of low flows and high temperatures.

ROLF ELIASSEN

III. BURNING PULP-MILL WASTE FROM SULFITE MILL

BY GROVER KEETH

Trans., Am. Soc. M. E., 61, 679 (NOV., 1939)

The Howard Process for the treatment of waste sulfite liquor has been installed at the plant of the Marathon Paper Mills Company, in Rothschild, Wisconsin. The sludge from the second stage of the process contains most of the lignin removed from the liquor and will range from 1,000 to 1,250 pounds dry weight per ton of pulp produced, depending on the kind of wood used and the details of the cooking operation. From a plant having a daily pulp production of 100 tons, this would mean a recovery of 50 to 65 tons per day of fuel product from the waste sulfite liquor. The author conducted many studies to determine the most economical method of utilizing this material to yield its maximum heat value. Special products derived from the precipitate have a limited market and in view of the large tonnage which would be obtained from many installations of the Howard Process in sulfite mills, the economics of the process depend upon the use of the lignin as boiler fuel.

As collected from the second stage of the Howard Process, the solids are essentially a colloidal organic material which is a basic calcium salt of lignin-sulfonic acid, together with some non-ligneous organic impurities. It has a calorific value of 8,000 to 8,500 B.t.u. per lb. dry basis, with an ash content of about 18 per cent. At its normal alkalinity of pH 11, it filters readily on a rotary vacuum filter to a cake containing 68 to 70 per cent moisture. An 8 ft. diameter by 12 ft. long Oliver filter is sufficient to handle 65 tons dry weight of this cake per day. Various endeavors with the present filter have been made to reduce the moisture content of the filter cake below 68 per cent. The colloidal character of the material and the tendency to shrink and check on the filter drum have prevented a further reduction. A cotton-duck filter cloth has given the best results, with a clear filtrate. At a moisture content of 70 per cent the cake discharges cleanly in flake form and appears quite dry. It is comprised of a chocolate-colored colloidal organic material in flocculated condition. Although it appears dry, it may be

mixed by a rapidly moving impeller which readily puddles it to a semi-fluid paste which can be pumped by a screw pump.

Early experiments with small amounts of dried material led to the belief that it could be used as a fuel if the moisture content could be reduced to 50 per cent. It was also shown that below 58 per cent the material would not puddle. The greatest problem was to find an economical method to reduce the moisture content of 65 tons dry weight per day from 70 to 50 per cent. The high tonnage requirement and the non-fibrous colloidal character of the filter cake eliminated any press of standard design. Four methods were given consideration as follows: (1) Parially or wholly drying the filter cake in fuel-fired direct heat driers of the rotary or other type. This is practical but expensive on account of the high moisture, with a consequent high fuel requirement for evaporation. (2) Partially or wholly drying the cake in a steam-heated tubular rotary drier, such as is in common use for drying brewery products. Economical drying can be accomplished by this means, provided the drier can be located alongside the boiler in which the fuel product is to be burned, thereby permitting the return of the high-pressure condensate to the boiler. The sensible heat in the product as it discharges from the drier will be saved and heat will also be recovered from the vapor discharge of the drier. Satisfactory experiments for this type of work were conducted at the plant. (3) Partially or wholly drying the cake with boiler-stack or other waste heat gases. This is theoretically an economical procedure since no charge is necessary for the waste heat gases. However, the available heat for drying in stack gases at 300 to 400° F., as produced from modern boiler plants, is rather low. Consequently, large volumes of such gases would be required for even the partial removal of water from a filter cake containing 70 per cent moisture. (4) Removing water by pressing the cake mechanically. This would seem the most economical method of reducing the moisture content of the fuel cake, provided it is feasible. Experiments were conducted at the Marathon plant by the author to develop this method on a commercial basis.

Laboratory pressing tests indicated that the moisture content of the filter cake could be reduced from 70 to 50 per cent by pressing at 200 lb. per sq. in. with one minute retention under pressure for a one inch cake. Higher pressures failed to reduce the water content further, from which it was concluded that all of the free water had been removed. A continuous press was developed after much experimental work. In principle this press is constructed of a vertical wedge-shaped chamber in which the material is pressed in its downward travel between two belts approaching one another. The belts are endless and tractor-like in construction and are made by attaching grid sections with perforated metal faces. Two endless, loose-woven cotton belts 48 in. wide travel with the grid belts downward through the compression chamber and are supported on the perforated face of the grid. These serve as the filtering media. Photographs are included in the article to illustrate the construction of this press. It was designed for a maximum working pressure of 250 lb. per sq. in. on the material and for a belt travel of 12 ft. per minute. At this speed the press can handle 70 tons dry weight of sulfite cake per 24 hours.

This lignin fuel product apparently contains no low-temperature volatile organic matter. This makes it slow to ignite in comparison with bituminous coal. The combustion characteristics are such that above a critical decomposition temperature the lignin material gasifies directly and completely into what are probably carbon monoxide and hydrogen, which burn readily over the fuel bed. Attempts were made to burn this material on underfeed stokers. With 25 per cent lignin and 75 per cent coal severe slagging occurred and the method was abandoned. Investigation was also made with an inclined grate Dutch-oven furnace for wood burning. If the material were wet it would stick at the top of the grate; if dry enough not to stick, it burned too unevenly. Mixtures of lignin and fuel oil were tried with the result that the oil burned, leaving the cake in the furnace.

Best results were obtained with spreader type stokers which had been installed in the existing boilers. It was found that successful results could be obtained as long as the fuel was in the range close to 50 per cent solids and a mixture of approximately 15 per cent coal and 85 per cent lignin was fed to the stoker. Neither of the two fuels

was pulverized for use with the spreader type stoker. For mills equipped with coal pulverizers no definite recommendations can be made without further study. By reducing the moisture content of the lignin to 50 per cent in a filter press it is only possible to render the material suitable for stoker feed. Tests indicate that it cannot be handled in a mill with close clearances such as modern pulverizers have. An open type mill will give good pulverizing action but the power consumption is high and capacities are low. Pulverizing tests were carried out at five different plants using three types of pulverizers. The success of the stoker has been established to the extent that it is the accepted means of burning this fuel.

After two years of burning this lignin fuel at the Marathon Mills no indication of boiler corrosion has arisen, even though most of the burning has been done in one boiler. The alkaline character of the fuel is of considerable influence as a protective factor. The firebrick for the boiler comes from the Missouri field and is not affected by alkali fumes. However, if the furnace lining were acid it would flux rapidly with ash. It is necessary that the proper firebrick be used. The high lime content of the ash makes it necessary to be careful of dust leaks from breechings and flues in order to protect the nostrils of the workmen. The ash must be kept dry in order to prevent the formation of mortar in the ash tank. A steam vacuum removal system has been found to be most adaptable.

Continuous operation of the boiler far in excess of its normal rating is possible with this fuel. During an efficiency test an average of 26,039 lb. of steam per hour was generated in a 386 H.P. Stirling boiler equipped with a stoker having 96 sq. ft. of active area and a furnace volume of 1,003 cu. ft. This was equivalent to 185 per cent of the boiler rating. The engineers believe that this figure could have been exceeded if more fuel had been available but they were using the entire output of the mill. The results showed that 3.64 lb. of steam were evaporated per lb. of fuel. Theoretically, 6.48 lb. of steam should be obtained. This means an efficiency of combustion and evaporation of 64 per cent. In other words, 64 per cent of the available heat has been recovered from the lignin material precipitated in the second stage of the Howard Process. This represents a substantial economy figure in plant operation.

ROLF ELIASSEN

THE CONTROL OF FILTER FLIES ON PERCOLATING FILTERS

BY K. A. MURRAY

Sewage Purification, 2, 21 (1940)

On the basis of experience gained with closed filters at Germiston, South Africa, the author reports that enclosing a filter maintains a more uniform temperature in the filter with consequent increase in fly breeding. These flies find their way to the atmosphere via the false floor of the filter and air ports. The author refutes the opinion that high-rate filtration prevents excessive fly breeding by drowning them. The bodies and wings of *Pyschoda* are not wetted with water and their bodies are so light that the surface tension of the water is sufficient to support them on the surface of the water. Even with large quantities of soap solution, it is impossible to drown them. Paraffin added to the water reduces the surface tension of the water sufficiently to wet and drown the flies.

Note.—In the February issue of the *Sewage Purification*, a letter to the Editor is published from M. Lundie of the Enclosed Sewage Treatment Co., in answer to Murray's article. Here it is admitted that enclosing a filter and high rate of dosage give rise to increased fly breeding and it is suggested that screening the exhaust air ports at the base of the filter makes it possible to prevent the emergence of the flies to the atmosphere. Since this rquires considerable labor in cleaning the screens the correspondent suggests the construction at the base of the enclosed filters a circular exhaust air duct into which the ports discharge. In this duct are placed at suitable intervals large openings covered with movable screens.

H. HEUKELEKIAN

MATERIALS FOR A STUDY OF ANIMAL COMPETITION.

THE FAUNA OF THE SEWAGE BACTERIA BEDS

By L. L. Lloyd, J. F. Graham, and T. B. Reynoldson

The Annals of Applied Biology, 27, 122–150 (Feb., 1940)

A systematic study of the occurrence and number of larvae and pupae of the different types of filter beds fauna at Knostrop sewage works of the Leeds corporation were made. These were coupled with laboratory studies of the fertility at various temperatures and direct observations on the predacity of the types on each other. The deviation from the expectation of the numbers of different types were attributed to the competition and predacity within the bed, taking into account the numbers passing out in the effluent. A description is given on the habits, life cycle, carnivorious tendencies of *Lumbriculus lineatus, Psychoda sivcrini, Psychoda alternata, Spaniotoma minima, Spaniotoma perennis, Metriocnemus longitarsus* and *Metriocnemus hirticollis*.

The seasonal abundance of the flies is governed by (*a*) temperature, (*b*) food supply which is regulated by the density of population and (*c*) "interference" which may be direct attack or due to the activities of the larvae and worms loosening the attachment of the organisms to the food. Actual devouring of organisms in the absence of other food was shown by *Metriocnemus longitarsus* (65 per cent cases), *Spaniotoma minima* (62 per cent cases), *Psychoda sivcrini* (39 per cent cases) and *Psychoda alternata* (12 per cent of the cases). Thus *chironomids* are more prone to carnivorous habits than *Psychoda*. Thus carnivorous habits have to be reckoned with especially after unloading when food is scarce. Psychoda eggs being deposited in the film chironomid larvae eat them as they graze. Thus when *chironomids* are abundant, *Psychoda* are less abundant. This generalization applies to beds at different localities or to an abundance and zoning of *Psychoda* vertically within a bed. *Psychoda alternata* can make only slight counter attack on the competing organisms because of its lesser predacity. Loosening effect of one organism on another is an important factor in the competition. Eggs, pupae and worm cocoons are loosened from the medium by the activities of the grazing organisms and the numbers washed away from the beds may be in part due to such interference. Most of the loss of larvae by this means however is associated with the spring unloading and is due to the worms and larvae following the food they have loosened to the bottom of the bed. At this time scouring reduces the available food and fly breeding is checked in consequence. The beds become choked unless scouring organisms keep pace with the accumulation of film. Resting of a choked bed gives the scourers a chance to regain control. If the sewage is fed to a choked bed it becomes foul and unsuitable to scourers. These organisms cannot reopen an impervious bed. Beds are kept open by various combinations of scouring organisms at different locations.

When the fauna is mixed and varied there is less chance of aerial nuisance of *Psychoda* preventing excess breeding of flies.

It is indicated that the fauna may have more than a mechanical function in beds, that metabolism of the organisms may also be of importance.

H. Heukelekian

THE EFFECT OF CHROMATE ON THE PURIFICATION OF SEWAGE BY TREATMENT IN BACTERIAL FILTERS

By S. H. Jenkins and C. H. Hewitt

Jour. Soc. Chem. Ind. Trans., 59, 41–44 (Feb., 1940)

The presence of chromium in Birmingham sewage, amounting on one occasion to about 90 p.p.m., led to this investigation. The chief sources of chromium compounds in sewage are from the discharge of waste from chromium plating processes and from ano-

dizing processes using chromic acid as the electrolyte. B.O.D. values of sewage containing as little as 2.6 p.p.m. of chromium as K_2CrO_4 (after dilution) was markedly depressed. Reduced chrome salts, chrom alum, basic chromium sulfate had a more marked depressing effect on B.O.D. than chromate. This may be related to the rapid coagulating effect of reduced salts of chromium on sewage solids causing a reduction in the strength of sewage. Sewage containing 100 p.p.m. of chromium in the form of chrom alum gave a reduction in oxygen absorbed value of about 50 per cent in the supernatant liquor after settling.

The experiments on the effect of potassium chromate in sewage on the purification by trickling filters were conducted in glass tubes 5 ft. long and 1¼ inches in diameter. The medium was ¼–½ in. quartzite. The nominal rate of application was 60 gallons per cubic yard of the medium. The filters were matured for a period of 20 days with applications of sewage free from chromate. To four matured filters potassium chromate additions were made to the applied sewage as follows 1 = 0.2 = 1.0 p.p.m. Cr.; 3 = 10 p.p.m. Cr. and 4 = 100 p.p.m Cr. The results showed that 1.0 p.p.m. Cr. as K_2CrO_4 affected nitrification and purification somewhat. The action was insufficient to impair the quality of a good effluent. With 10 p.p.m. Cr. nitrification and oxidation of organic matter was appreciably reduced. It was sufficient to convert a good effluent into one of relatively moderate quality. At 100 p.p.m. concentration nitrification was reduced 66–78 per cent and the effluents contained 186–242 per cent more organic impurity than in effluents from the control filter. The upper part of the filter receiving 100 p.p.m. chromium contained about twice as much deposited solid matter as the control filter receiving no chromate. The dry solid matter contained 5.2 per cent of chromium equivalent to the removal of 12 p.p.m. of chromium from sewage.

H. HEUKELEKIAN

THE ECOLOGY OF ACTIVATED SLUDGE IN RELATION TO ITS PROPERTIES AND THE ISOLATION OF A SPECIFIC SOLUBLE SUBSTANCE FROM THE PURIFIED EFFLUENT

BY N. W. BARRITT

The Annals of Applied Biology, **27**, 151–156 (Feb., 1940)

The number of types of bacteria, fungi and protozoa decreases as activated sludge develops. Sludges obtained from different sources have practically the same protozoan fauna, namely Aspidisca, Epistyles, Carchesium and Vorticella. A sludge consisting of dispersed bacteria having a greater surface area is less effective in removing organic matter than one consisting only of bacterial zoogloea. Overaeration of sludge decreases the number of protozoa which do not feed on the floc. It is suggested that the fauna takes an active part in the direct removal of organic matter in solution and does not live chiefly by ingestion of bacteria.

Mixing solutions of sugars with activated sludge brings about an initial reduction in their concentrations. On shaking these mixtures in the absence of air further reductions are brought about which are not as high as when air is used. This indicates that even soluble materials are first adsorbed before they are oxidized. However long-continued absence of oxygen from the sludge destroys the adsorptive power and may result in the liberation of adsorbed material into solution again.

The production of gelatinous matrix by *zooglea ramigera* is independent of the composition of the nutrient solution and is not stimulated by the addition of sugar. This organism cultivated in liquid culture medium grows in dispersed form without any gelatenous matrix.

There is a small residual amount of organic matter in the finished effluent which has a higher oxygen consumed value than B.O.D. The virus of tomato disease has also a higher oxygen consumed value than B.O.D. The organic matter found in the effluent and the tobacco mosaic virus are resistant to enzyme action. It is stated that these

viruses survive aeration with activated sludge. From the purified effluent of activated sludge tanks treating milk waste was isolated a substance that resembled tobacco mosaic virus showing the property anisotropy of flow when agitated between crossed nicols indicating the presence of asymmetric particles. This property is not destroyed by heating to 100° C. but is lost in the case of virus. Effluent from trickling filters treating sewage yielded a substance with identical properties. These materials isolated from sewage effluents had no infectivity for plants. The substance is also obtained from activated sludge and is probably a water soluble substance of zoogleal bacteria.

H. HEUKELEKIAN

THE EFFECT OF BUBBLES OF GAS ON MIXTURES OF SEWAGE AND ACTIVATED SLUDGE

BY E. WILLIAMS

Jour. Soc. Chem. Ind. Trans., 59, 39–41 (Feb., 1940)

This is a continuation of the inquiry regarding the effect of passing different gases on the removal of organic material from sewage. In the present study comparisons are made of removals effected by the different gases from sewage and from activated sludge-sewage mixtures.

The different gases were passed through a liter of sewage or mixture at the rate of 25 liters per hour. The gases employed were air, oxygen, hydrogen and nitrogen. Approximately the same amount of organic carbon was removed from sewage liquor alone by treatment with each of the four gases for 6 hours. With air or oxygen the presence of activated sludge greatly increased the rate of removal of matter from the liquid. There was only a small removal of organic matter from mixtures of activated sludge and sewage treated with hydrogen or nitrogen. The removals effected by the latter gases were noticeable only during the first one or two hours, thereafter the organic matter previously flocculated became dispersed.

H. HEUKELEKIAN

SLUDGE TREATMENT METHODS

A REVIEW OF PRESENT-DAY PRACTICE (IN ENGLAND)

BY W. D. HAWORTH

Sewage Purification, 1, 436–443 (Oct., 1939)

The treatment and disposal of sewage sludge presents a problem upon which engineers and chemists have labored ever since the beginning of the collection and treatment of sewage.

Land treatment of sewage, offering a natural solution to the sludge disposal problem, was at one time highly popular, but the large land area requirements and frequent nuisance conditions associated with this method led to its supersedure. Barging of sludge to sea offered a convenient solution for coastal towns and London, Manchester and Glasgow have long availed themselves of this method.

For communities where barging to sea was impracticable, there developed the use of sludge lagoons or drying beds. These are usually constructed of about 12 in. of graded clinker with underdrains. Lagooning of sludge continues to be very general in use although productive of odor nuisance and subject to serious dislocation from weather. Where digestion is practiced the lagooning of sludge is considerably more satisfactory. The true remedy for the troubles of the sludge lagoon appears to lie in its replacement by a method capable of producing a product more suited to agricultural purposes.

In the North of England, where trade wastes are prevalent, filter pressing of sludge has long been in vogue, but is not considered applicable to humus or activated sludges. At Leeds there are sixteen presses, yielding 144 tons per day of pressed cake of 57 per cent moisture content. The sludge is conditioned with about one per cent of CaO; chlorination of the sewage in summer has been found to assist the press operation by delaying fermentation of the settled sludge. As an alternative to presses, vacuum filters have become popular. Ferric chloride is considered the best sludge conditioner. Until recently the cost of conditioning chemicals has retarded development of vacuum filtration but the elutriation process has removed much of this disadvantage.

For the digestion of sludge, Imhoff tanks are being superseded by separate units, arranged to operate in one or more stages. At the Mogden works, settled sludge is passed thourgh thickening tanks, thence to heated primary digesters and on to unheated, open tanks prior to drying on the open sludge beds. The gas collected from the primary tanks is used for power generation. At Manchester also, two stage digestion is practiced, the primary units being fed a mixture of 50 per cent preheated raw sludge and 50 per cent seeding sludge. Satisfactory digestion can be obtained with a 10 to 12 day period in the primary units.

The Henry process, developed in Belgium, is worthy of note. The mixing of caustic soda and a solution of starch, in a frozen state, with the sludge effects a ready separation of the associated water upon sedimentation. The thickened sludge is further dewatered on vacuum filters.

Among the processes for producing dried sludge, the Porteous process is attracting considerable attention as being suitable for use at medium sized works as well as large ones. The process consists of cooking the sludge at high temperature and pressure, thus effecting the ready separation of a large percentage of the water from the solids. Much of the heat is recovered in special heat exchangers. After decanting the separated water, the thickened sludge is filter pressed and the cake is air dried for later utilization as fuel or fertilizer. When used as fuel, the process ordinarily will be self-supporting in the matter of combustion.

V. G. MacKenzie

MUNICIPAL ENGINEERING IN 1939

Sewerage and Sewage Disposal Section

The Surveyor, 97, 68 (Jan. 26, 1940)

This article is a review of activities in this field in 1939; a listing of over 50 major works contemplated and in progress is given and mention is made of important technical papers and discussions of the year.

Great activity in connection with sewerage and sewage disposal schemes continued through 1939. The ministry of Health approved loans for projects of this type for £6,527,000, which compares with £6,993,831 sanctioned for the previous year. The outbreak of war in September caused the postponement of many schemes but this loss was partially offset by new work necessitated by evacuation of population from vulnerable to safe areas.

The incidence of war has required careful consideration being given to air raid precautions as affecting sewerage and sewage disposal. Technical papers have been presented on the subject which also has been dealt with in a government circular.

Interest in the activated sludge process has continued, as evidenced by a number of papers on this subject published during the year. In one of these the Kessener brush aeration plant at Stockport, the first installation of this type in England, was described as being very efficient and economical.

The past year has shown increased use of sludge digestion, the tanks commonly being unheated at small works. Production of power from sludge gas continues to be of wide interest.

Significant reports were presented during the year on percolating filter operation, particularly in regard to high rate dosage, double filtration, effect of temperature, and the economics of covering filters.

Trade wastes treatment formed the subject matter of several papers, particular interest being shown in metal processing plant wastes. With increasing armaments production, acid wastes have increased in importance.

V. G. MacKenzie

THE VALUE OF TREATED TOWN'S REFUSE AS AN ORGANIC MANURE

By E. H. Tripp

Chemistry and Industry, **58**, 1102 (1939)

The experiments in this article were undertaken by the Rothamsted Experimental Station in England to investigate the fertilizing value of the manure that is being prepared from refuse of Royal Borough of Kensington. The refuse is dumped into pits. It is picked up by a grab and transferred to the top of towers, whence it passes to belt conveyors. Unwanted materials such as glass, paper, metal, rags, etc., are picked out by hand. It is pulverized in large rotating cylindrical crushers, screened, sprayed with bacterial culture solution and conveyed to large cells, 180 ton capacity, where for 16 days it undergoes anaerobic and aerobic fermentation. The temperature rises to 170–175° F., gases are removed through flues and there is no objectionable odor. The plant is designed to treat 250 tons of refuse a day and yield about 160 tons of manure, "Hyganic." The percentage of dry matter in the manure varied from 63.9 to 74.4 (average 70 per cent) percentage of nitrogen in the dry matter from 0.97 to 1.42 (average 1.16). The "Hyganic" was tested in different soils for the growth of kale and sugar beets, potatoes and mangolds and compared with ammonium sulfate and farmyard manure. The organic manures were added on the basis of equal weights of nitrogen per acre (0.8 and 1.6 cwt. of N per acre and $(NH_4)_2SO_4$ on the basis of 0.4 and 0.8 cwt. of N. per acre). Hyganic when applied to kale and sugar beets gave higher yields than farmyard manure on the basis of equivalent nitrogen applications. On sugar beets the two organic manures gave similar increases in yield. On equal nitrogen basis Hyganic was superior to farmyard manure three times out of four to a statistically significant extent.

The Hyganic is sold at 9 shillings per ton.

H. Heukelekian

LOS ANGELES PLANS TO SPEND $32,000,000 FOR HANDLING SEWAGE

Eng. News-Record, **124**, 315 (Feb. 29, 1940)

The City of Los Angeles has retained a board of consulting engineers consisting of Samuel A. Greeley, Charles Gilman Hyde, and Franklin Thomas to survey the sewerage and sewage disposal problems of the city. This board has recommended that $17,580,000 be appropriated for immediate improvements and that $14,060,000 be allotted for deferred construction. A table is presented to show the breakdown of the estimate which totals nearly $32,000,000.

For sewerage improvements an expenditure of $12,804,000 is outlined. This includes an extension of the ventilation of trunk sewers where deterioration has been caused by hydrogen sulfide gas. The construction of a new ocean outfall, as well as the repair and enlargement of existing outfalls is also contemplated.

The valuable beaches on Santa Monica Bay are now subject to heavy pollution from 250 M.G.D. of screened sewage discharging at Hyperion. One of the outstanding considerations is the reclamation of this recreational area for public use. If present sewage

disposal plans were continued, by 1980 there would be a discharge of sewage from a tributary population of 4,000,000 at one point, resulting in an increased menace to the beaches. In order to prevent this condition, and to relieve the overload on the 55 mile long trunk sewer, the board recommends the immediate construction of two activated sludge plants at a considerable distance from the ocean. One should be located in the lower San Fernando Valley near Burbank, with a present capacity of 35 M.G.D. The effluent could be spread on gravel beds and would percolate into the ground water. Another plant of 40 M.G.D. capacity should be constructed at Vernon, with the effluent discharging into the Los Angeles River channel. By the diversions made at these plants the total sewage flow would be appreciably decreased.

For the future, an expansion of the above plants to capacities of 60 and 50 M.G.D., respectively, is contemplated. A third plant may also be necessary in a location about six miles west of the center of the city. The board suggests the purchase of the land now and the construction of a small plant to hold the rights for future use.

The main plant will be built at Hyperion near the existing screening plant. Immediate construction is recommended for a plant to treat 170 M.G.D., with a future capacity of 250 M.G.D. A new ocean outfall 5,000 feet long will be constructed to handle the effluent from this plant. These developments should provide adequate beach protection and open up new recreational areas.

Population estimates have been made by the city engineer. The present population tributary to the Hyperion outfall is 1,590,000; by 1980 this should be 4,000,000. The average daily sanitary flow is 82 gal. per capita, with a peak of 205 gallons. 1980 figures are forecast as 85 gal. and 212 gal., respectively. Allowances have been made for the conversion of agricultural areas into residential zones.

ROLF ELIASSEN

LAMINAR FLOW OF SLUDGES IN PIPES

BY H. E. BABBITT AND D. H. CALDWELL

Univ. of Illinois Eng. Exp. Sta. *Bulletin* No. 319, 60 pages (Nov. 14, 1939)

This paper presents a report of an investigation of the laminar flow of sludge in pipes with special reference to sewage sludge. The purposes of this investigation were to formulate the factors that influence the frictional losses in the flow of sludge through a circular pipe, to formulate the factors that affect the critical velocity, to verify the formulas experimentally, and to present a simple method for measuring the characteristics of individual sludges. Such materials as sewage sludges, aqueous suspensions of clay and sand in dredging, wood pulp suspensions in the paper industry, and drilling mud in well drilling operations may be required to be pumped through pipes, and for design purposes the frictional losses must be evaluated.

In order to develop a rational formula it is necessary to distinguish between viscous and plastic flow, and to observe in which category sludges belong. Viscosity is the measure of the resistance to flow or deformation of a fluid, the rate of deformation being a linear function of the deforming force. The coefficient of viscosity of a fluid is equal to the tangential force on a unit area of either of two horizontal planes at a unit distance apart required to move one plane at a unit velocity with reference to the other plane, the space between being filled with the viscous fluid. Assuming that μ is the coefficient of viscosity, S the tangential unit shearing force, x the distance between the planes, and v the velocity of one plane with respect to the other, the formula for the coefficient of viscosity becomes:

$$\mu = \frac{Sx}{v}$$

Plastic materials are sometimes erroneously considered to be merely very viscous substances. Unlike viscous fluids, plastic materials are not moved by very small shear forces. Deformation does not begin until the yield value is exceeded. After deforma-

tion has started, equal increments of stress will produce equal increments in velocity, similar to the property of viscous substances. Using the fundamental concept of flow between two parallel planes, and taking into account the applied force S used in overcoming the yield value S_y, the equation for the coefficient of rigidity, η, becomes:

$$\eta = \frac{(S - S_y)x}{v}$$

The authors present curves showing the flow characteristics of true liquids, pseudo-plastics, true plastics, and inverted plastics. It has been found in this investigation that the flow of sludge follows the characteristics of the curve for plastic flow very closely, thus permitting the conclusion that sewage sludge is a true plastic.

Assumptions were made that the conditions affecting the friction resulting from the laminar flow of sludge in a circular pipe are the following: V, the mean velocity of the sludge; D, the diameter of the pipe; L, the length of the pipe; ρ, the density of the sludge, η, the rigidity; and S_y, the yield value. The pressure and temperature will be assumed to affect the friction only through their effect on the characteristics of the sludge. In the laminar flow of fluids, the roughness of the pipe wall does not affect the friction loss. As in all laminar flow, the friction loss will be assumed to result only from the rubbing of the sludge layers past each other and not from kinetic energy losses.

A complete mathematical analysis is presented to formulate the factors affecting the flow. It is shown that the sludge flowing in the center of the pipe moves as a solid plug, resulting from the fact that the shear between the moving layers increases from zero at the center of the pipe to a maximum at the pipe wall. At some distance between the center and the wall the shear will be equal to the yield value of the plastic sludge. Where the shear is less than the yield value there will be no relative motion between adjacent particles which will, therefore, flow together as a solid plug. The analysis continues, with certain approximations to get rid of infinitesimals, until a formula is developed which gives the head loss H, in feet of flowing substance as:

$$\frac{H}{L} = \frac{16\,S_y}{3\rho D} + \frac{V}{\rho D^2}$$

This equation has been checked by experiments in the investigation, and by using results from tests reported in the literature. A table is given to show the comparison between computed and observed values of head losses in pipes of various sizes. In most cases the agreement is within 5 per cent, sufficiently precise for practical purposes.

This formula holds true only in the region of laminar flow, which is below the critical velocity. The friction loss is directly proportional to the velocity below the critical velocity, while above this value it is directly proportional to some power of the velocity between 1.7 and 2.0. For circular pipes the flow will be laminar when the Reynolds number is less than 2,000. Above a number of 3,000 the flow is usually turbulent. Between these values of the Reynolds number there is uncertainty as to the type of flow which may occur. In order to distinguish between these two values, the velocity corresponding to a Reynolds number of 2,000 will be designated as V_{lc}, the lower critical velocity, and the velocity corresponding to a Reynolds number of 3,000 will be designated as V_{uc}, the upper critical velocity. A mathematical analysis leads to the following expression for these factors, expressed in terms of the characteristics of the sludge and pipe:

$$V_{lc} = \frac{1000\eta + 103\sqrt{94\eta^2 + D^2 S_y \rho}}{D\rho}$$

$$V_{uc} = \frac{1500\eta + 127\sqrt{140\eta^2 + D^2 S_y \rho}}{D\rho}$$

Tests were made to check the validity of these equations, using various pipe sizes and different sludges to observe the critical velocities. A table is presented showing a high degree of correlation between observed and computed values.

From the formulas developed for friction loss and critical velocity it is evident that it is only necessary to determine the yield value and the coefficient of rigidity of the sludge in order to be able to compute the above factors. Among the conditions affecting the yield value and coefficient of rigidity are concentration of suspended matter, size and character of particles of suspended matter, nature of the continuous phase, temperature, thixotropy, slippage and seepage, agitation, and gas content.

The tests made in this investigation show that the concentration of suspended matter greatly affects the yield value, and affects the coefficient of rigidity to a lesser degree. When the concentration of suspended matter is low the material may exhibit no measurable yield value, but as the concentration is increased a yield value appears and increases almost in direct proportion with the concentration. When the suspended particles are not in contact no yield value exists, but as concentration increases, contacts increase, causing the particles to slide over one another, giving a yield value. The net effect of an increase in solids concentration is to increase the resistance to flow of the material. There is abundant evidence that as the diameter of the particles is decreased, the opportunity for the particles to come in contact with each other is increased, increasing the yield value. Most of the sludges considered in this investigation were mixtures of particles of solids suspended in water. Sludges may be composed of a mixture of solids suspended in some fluid other than water. The coefficient of rigidity and the resistance to flow of a sludge depends on the viscosity of the fluid which comprises the continuous phase. Experiments have shown that the fluid has no effect on the yield value provided the percentage of suspended matter remains constant, and as long as the continuous phase is inert with respect to the suspended particles. Temperature has a marked effect on the viscosity of fluids. The effect on a sewage sludge of a rise in temperature is to reduce the yield value and the coefficient of rigidity.

In measuring the coefficient of rigidity and the yield value of a sludge it is essential that their changes due to agitation be controlled, otherwise a true measurement cannot be obtained. This is caused by the phenomenon known as thixotropy, the property exhibited by some gels of becoming fluid when shaken. Through the use of a long tube viscometer, errors of this nature were avoided in these experiments. Agitation may also change the size of the particles in the mixture, rearrange or distribute them. The pumping of sludge through reciprocating, centrifugal, or rotary pumps is a common cause of agitation and may decrease the resistance to the flow of sludge. One of the assumptions made in the development of the laminar flow equation for sludges was that no slippage occurred at the pipe walls. Slippage is rare with the laminar flow of sludges but may occasionally be noticed where the pipe wall is glass smooth and the yield value is high. Errors from this source were overcome by using pipes which were not too smooth. Seepage is the flow of the continuous phase through the dispersed solids and is relatively unimportant in pipes larger than capillary tubes. Bubbles of gas in the sludge will affect the density of the mixture. Density is of importance in turbulent flow but theoretically has no effect in laminar flow.

The measurement of the values of S_y and η may be made in a number of ways. Any existing pipe line through which the sludge may be pumped can be used by measuring the friction losses between any two points in the line and applying the proper formulas and interpretation of the graphs plotted. The authors have an extensive discussion of this method. The Stormer viscometer can be adapted to the measurement of the coefficient of rigidity and the yield value by slight modifications to prevent binding of the rotating cylinder by the sewage sludge. An explanation and illustration of this apparatus is given, together with formulas and procedure for analysis of results. Other viscometers may also be used, including the rotating cylinder type, the falling ball viscometers, swinging pendulums, or capillary tubes, not all of which are adaptable for use with sewage sludge.

The authors present a detailed description of the apparatus used in their tests, including their preliminary set-up, difficulties encountered in making measurements, the clogging of gages and means of eliminating these difficulties. The long tube viscometer consisting of a $\frac{3}{8}$ in. drawn brass tube 36 in. long was adopted for the final tests. Among the important findings resulting from the tests with this viscometer were the true

plastic properties of sludges and the yield values and coefficients of rigidity of the sludges tested. Tests at Decatur, Illinois, are also described, with considerable data. A special circulating apparatus consisting of lengths of three different diameters of pipe was also used for measuring the values of S_y and η. A rotary pump was found most satisfactory for controlling the flow. Losses of head were noted in each pipe and computations made. The results indicated that S_y and η are independent of the diameter of the pipe in which they are measured.

Heretofore no formulation of the factors affecting the friction loss in the flow of sludge through straight circular pipes has been available. These experiments have given important data with regard to the characteristics of sludges, together with their use in formulas which should prove helpful to the designer. Further research as to the factors affecting the turbulent-flow losses of sludges flowing in circular pipes is desirable. Present indications are that the common hydraulic formulas for the flow of water are not applicable to the flow of sludges.

ROLF ELIASSEN.

THE INFLUENCE OF ACTIVATED SILICA IN SEWAGE COAGULATION

BY CONRAD W. CHRISTENSON AND IRVIN LAVINE

Transactions of American Institute of Chemical Engineers, **36**, 71–90 (Feb. 25, 1940)

This paper gives the results of laboratory and plant studies carried out at Grand Forks, North Dakota. Thirty references relating to chemical coagulation are included.

Laboratory procedure used in this work was, with slight modification, that outlined by Baylis in his work with water. The term "activated" is used to describe those solutions of acidified sodium silicate which aid coagulation. Coagulating chemicals used in the experiments on coagulation were alum, ferric chloride, ferric sulfate, ferrous sulfate and bentonite. However, the work was mainly concerned with the benefits that might be derived by using acidified sodium silicate in conjunction with alum. In general, it was found that acidified silica imparts the same aid in coagulation when used with the ferrous salts as when used with alum under similar conditions. Ferric salts did not receive the same aid although the addition of the silica did improve the character of the floc. Bentonite was found to cause an increase in the turbidity of the supernatant liquid. In every test where silicate was used it was added in advance of the coagulant because it was found that such a procedure gave better results. It was found during the course of this work that silicate solutions must contain at least 1 per cent SiO_2 before they can be made active. Tests with 0.75 per cent SiO_2 solutions gave very poor results.

The silicate solutions were prepared by the method of Baylis. First laboratory tests were run with solutions of C.P. sodium metasilicate, $Na_2SiO_3.9H_2O$ containing 0.75 per cent SiO_2. Alkalinity of these solutions was 1200. Poor results (in some instances deflocculation) were noted with these solutions. Better results were obtained with solutions of lower alkalinity. Solutions were also prepared from commercial water glass. The water glass that was used analyzed 30.0 per cent SiO_2 and 9.5 per cent Na_2O conforming with general formula $Na_2O.3.25\ SiO_2$.

Baylis used the term "alkalinity" to designate the equilibrium of the acid-treated sodium silicate solutions. In the present work, however, the equilibrium is designated by the pH. The relationship between alkalinity and pH of silicate solutions was determined and the results are shown graphically.

The efficiency of coagulation was measured by (*a*) removal of settleable solids, (*b*) B.O.D. reduction, (*c*) turbidity reduction, (*d*) size of floc, (*e*) time required to form a large sized floc. Other tests such as removal of total solids, volatile solids, chlorine demand, quantity of sludge formed, were made in a few cases. The classification devised by Baylis for comparing the size of the floc was used, with some modification.

Results of Laboratory Experiments

1. *The Effect of pH of Silicate Solution.*—This pH influenced the time the solution had to stand after acidifying before it became activated, and deflocculation resulted in all cases where the original pH of the silicate solution was above 10, even with very long periods of ageing. The pH of the solution has little influence on the character of the floc and the turbidity of the supernatant liquid for solutions in the range 5.0 to 9.4 provided the silicate solutions are properly aged. The ageing period varies from a few minutes for a solution of pH 7 to several hours for pH 9. The ageing time for a 3.0 per cent silicate solution at 70° F. for various pH values is shown graphically. The curve passes through a minimum at pH 7.0 corresponding to an ageing time of about 10 minutes. At pH 5.0 the time was 140 minutes and at pH 9.5 about 90 minutes.

2. *Effect of Ageing of Silicate Solutions.*—Data are presented which show definitely the need for proper ageing of the silicate-solution used. Contrary to results reported by other investigators no deterioration in a solution having a pH of 8.6 was noted even after three months of ageing. The increase in pH of acid treated silicate solutions was investigated at 70° F. and results are presented graphically. An empirical equation showing the relationship between pH and time of ageing was developed.

3. *Effect of pH of Sewage.*—Data are presented in tabular form which indicate that the addition of silica widens the sewage pH zone for effective flocculation with alum. Good floc formation can be obtained at a pH as low as 4.9. In every case the floes formed in the acid range settled much more rapidly and completely than those formed in the alkaline range. The effect of the silicate solution in the extreme alkaline range could not be determined because the sewage formed a floc automatically at pH values above 9.3.

4. *Effect of Temperature on Ageing.*—The data presented indicate that the time of ageing can be materially reduced by increasing the ageing temperature from 70° to 180° F. Ageing for two minutes at 180° F. gives results that are about the same as obtained with a solution aged for sixty minutes at 70° F.

5. *Quantity of Silica.*—The effect of the quantity of silica was studied by treating the sewage with 50 p.p.m. of alum and with 5 to 100 p.p.m. SiO_2. Results indicated that only low silica dosages are necessary to give improved coagulation and that excessive silica deters rather than aids flocculation.

6. *B.O.D. Reduction.*—Typical laboratory B.O.D. reductions (30 min. mixing + 1 hour settling) were 30.0 per cent with no coagulation; 51.2 per cent with 50 p.p.m. alum alone; 52.3 with 50 p.p.m. alum + 10 p.p.m. SiO_2 solution having pH = 8.3, not aged; 73.5 per cent with 50 p.p.m. alum + 10 p.p.m. SiO_2, pH 8.3, aged one hour.

Grand Forks Plant Test

The Grand Forks plant provides for grit removal, aeration, primary sedimentation in two circular clarifiers operated in parallel, and separate sludge digestion. A two-day plant test run was made using alum only during the first 24-hour test and alum and acidified sodium silicate in the second 24-hour test. Sodium silicate used was commercial water glass. Alum was commercial alum as used by the city in water treatment and contained 26 per cent $Al_2(SO_4)_3$.

A 1.5 per cent silicate solution was prepared from water glass and sulfuric acid in 400 lb. batches. The pH was 8.8, ten minutes after addition of acid. Solutions became active after about six hours. To lessen danger of gel formation, solutions were diluted to 1 per cent concentration and then aged for 24 hours. pH of solutions at time of application was about 9.6.

Silicate solution was added manually ahead of alum at the inlet end of the grit chamber which was temporarily equipped with baffles to aid in mixing. Alum, silicate and sewage were then mixed for about 30 minutes by air in the regular mixing chamber and then passed to the clarifiers, which gave a detention time of two hours. Composite samples were taken of the influent and effluent for B.O.D., suspended solids, dissolved solids and volatile solids determinations. Hourly checks were made on the character of the floc, turbidity, pH, and settleable solids.

GRAND FORKS TREATMENT WORKS

Results of Two 24-Hour Tests

Results of Analyses, P.P.M.	Alum Only, 35 P.P.M.			Alum, 35 P.P.M. Silica, 10 P.P.M.		
	Inf.	Eff.	Per Cent Red.	Inf.	Eff.	Per Cent Red.
Suspended Solids	229	96	58.1	372	15	95.8
5-day B.O.D.	400	278	30.5	453	226	50.2
Turbidity	750	175	76.7	650	55	91.5

Editor's Note: The authors state that "the present (non-chemical) treatment results in a reduction of about 78 per cent in the turbidity and 93 per cent in suspended solids." Why was there only 58.1 per cent reduction in suspended solids when alum was used?

The paper is concluded with a discussion of the mechanism by which the specially treated silica aids coagulation. The action is probably between positively charged aluminum hydroxide and negatively charged silica particles. Since the charge of silica particles is more positive in the acid range, solutions of too low pH hinder coagulation because of floc dispersion. Presence of large amounts of alkali is believed to prevent formation of polymerized particles, leaving silica in a molecular state which does not aid coagulation.

PAUL D. HANEY

SEWAGE PURIFICATION AND DISPOSAL: BRITISH PRACTICE

BY DAVID MOWAT WATSON

The Surveyor, 96, 538 (Dec. 29, 1939)

For many years English sewerage practice has been molded on lines suggested by the Royal Commission on Sewage Disposal which served from 1898 to 1915. Although the recommendations of the Royal Commission were couched in general terms, many designers followed them rigidly for years with resulting lack of originality and probable loss of some valuable experience by the community.

The Ministry of Health functions as the central English authority which examines the proposals of local authorities as to reasonable adequacy and financial safety and, upon approval, sanctions the borrowing of the necessary money by the local agency.

Both separate and combined sewer systems are found in England but the most general type of system is the "partially separate," in which drainage from yard and certain roof areas is carried with the domestic sewage and trade wastes. This system has largely evolved from the recommendation of the Royal Commission that, during wet weather, the maximum flow conveyed to sewage works for treatment should be not less than six times the dry weather flow. This recommendation results in sewers which are larger than necessary to carry only the domestic sewage and trade wastes but not large enough to carry all the surface drainage. An unsolved difficulty, existing in varying degrees in many urbanized districts, is caused by the discharge, without treatment, of the foul first flushes of storm drainage to the receiving watercourse.

Local sanitary authorities, since 1937, are required to receive trade wastes into the public sewers for treatment when the manufacturer so elects to dispose of his wastes. However, in such a case, the public body may require conditions as to pretreatment and maximum rate of discharge and may impose special charges for handling the wastes. Local rulings are subject to review by the Ministry of Health upon appeal by the manufacturer, and the latter may, in any event, dispose of his own wastes.

In the disposal of sewage via sea outfalls, discharge without treatment is becoming less common. Disintegration of solid matter or sedimentation prior to discharge is growing in favor and is being recognized as sound practice.

With increased knowledge of activated sludge has come confidence in its performance, and the process is making progress for large and small works alike. Aeration by diffused air and by the Simplex system is proving more popular than other methods. Desire of the designer to lighten loads on the aeration units is manifested by the provision of efficient preliminary sedimentation and of means to dilute the influent by return of purified effluent. Installations for partial purification by activated sludge preceding bacterial filters have been built at a number of plants as a means of increasing the plant capacity.

Biological filters are firmly established in England, as elsewhere in the world. Recent experimentation on high rate filtration, on two-stage filtration with alternation of the first and second stage units, and on covered filters has reawakened interest in the subject of the maximum loading which these units can bear.

The commonest method of sludge treatment is digestion in separate tanks, but collection and utilization of the gas is not universal, particularly for smaller plants. Digested sludge is commonly dried on open drying beds.

V. G. MacKenzie

REPORT ON SANITARY ENGINEERING PROJECTS—1939

By E. F. Eldridge

Bulletin, Michigan Engineering Experiment Station, 87, 1939

The Biological Filtration of the Phenolic Wastes from a Gas Plant

Experimental studies were made on a laboratory trickling filter 3 ft. deep, with an area of 1.4 sq. ft., using synthetic phenol wastes made by dissolving known weights of phenol in tap water. This phenol solution was applied to the filter at a rate of 1 m.g.a.d. The results indicated that complete removal could be obtained with concentrations of 20 to 30 p.p.m. The greatest removal of phenol was 4.7 lb. per 1,000 cu. ft. of filter media at concentrations from 100 to 115 p.p.m. Concentrations up to 180 p.p.m. were entirely removed by two-stage filtration. Above 200 p.p.m. the filter efficiency decreased considerably, even with two-stage filtration.

Further studies were made on gas plant scrubber liquor from the ammonia still at the Battle Creek Gas Co. plant. The phenol content of the liquor averaged 1,932 p.p.m. during the two months of the test. A trickling filter 6 ft. deep with an area of 16 sq. ft., having stones 2 to 3 in. in diameter, was used. The high phenol content necessitated dilution of the waste liquor with river water or sewage. These also furnished organisms for seeding the filter. The results indicated that gas plant wastes contain toxic materials other than phenolic compounds. These accumulate on the filter media if wastes having more than 50 p.p.m. phenol are applied, but have no effect if kept between 30 and 40 p.p.m. For complete removal of phenol the feed to the filter should be below 30 p.p.m. Sewage seeding gave better removals than river water, the sewage giving more organisms to the filter. The results also indicate the desirability of using two-stage shallow filters rather than deeper single stage units.

To apply this method successfully to the conditions at the Battle Creek Gas Co., with a waste having 1,932 p.p.m. of phenol would require dilution to a filter feed containing only 30 p.p.m., or 1 to 64. With a volume of waste of 10,000 gal. per day, this would mean furnishing 640,000 gal. of water or sewage. The cost would be so great that consideration should be given to other means of phenol removal. For plants having low phenol concentrations in their waste liquor, biological filters might prove to be an economical method of treatment.

A Full-Scale High-Rate Recirculating Filter for Milk Waste

This paper describes the treatment plant at the Borden Company Condensery at Perrington, Michigan, originally designed as a low-rate filter preceded by a holding tank to permit uniform dosage of the filter at 1 m.g.a.d. The filter is 7 ft. deep, with an area of 1,027 sq. ft. This was converted to a high-rate recirculating filter by installing a pump and adding new filter rock 2 to 3½ in. in diameter to replace the smaller media originally installed. The waste from the milk plant averages 30,000 gal. daily and comes in 8 hr. at a rate of about 60 gal. per minute. From the holding tank a centrifugal pump applies the waste through a 36 ft. diameter rotary distributor to a filter at a constant rate of 285 gal. per minute. A final settling period of only 8 min. follows the high-rate filter. Most of the liquor returns to the holding tank, but some overflows from the final settling tank to the outfall sewer, equal to the flow entering the holding tank from the factory. During the day the waste is recirculated an average of 5 times over the filter. This is equivalent to a rate of application of raw sewage of 3.4 m.g.a.d., or a total rate of 16 m.g.a.d., including raw sewage and recirculated liquor. At night, with no flow entering the plant, continuous recirculation still takes place, reducing the B.O.D. of the liquor in the 13,500 gal. holding tank to provide dilution for the strong waste entering in the morning.

With the standard low-rate filter an average B.O.D. reduction of 60 per cent was obtained over a period of several years. The new recirculating filter gave an average B.O.D. reduction of 90.6 per cent, from 537 to 46 p.p.m. The average B.O.D. of the waste applied to the filter after dilution with final settling tank effluent was 106 p.p.m. Suspended solids reductions of 77.1 per cent were obtained, from 484 to 92 p.p.m. Higher reductions of suspended solids, and possibly B.O.D., could have been obtained if a longer detention period had been provided in the settling tank. However, with only a few changes in the plant layout, the removal of B.O.D. was increased from 60 to 90 per cent through the use of the high-rate recirculating filter.

The Beet Sugar Factory Waste Treatment Plant of the Monitor Sugar Company

After considerable experimental work the waste treatment plant of the Monitor Sugar Company at Bay City, Mich., was designed and recently completed. The plant is designed to handle 5 m.g.d. of flume water, beet washer water, battery wash water, and pulp press water. All of the wastes are mixed before reaching the plant. These flow first through a revolving screen with 1/16 by 1/2 in. slots to remove the larger particles. About 30 cu. yd. are removed daily, or 6 cu. yd. per m.g. The waste then flows through a grit chamber designed for a velocity of 1 ft. per sec., with a length of 53 ft. Scraper mechanisms remove the grit to a conveyor belt, 33 cu. yd. being removed daily with a solids content of 17 per cent. No attempt is made to separate the organic matter from the remainder of the grit. Previous experiments had shown that Steffens house waste would be a good coagulant for the remainder of the factory waste. Coagulation tanks are provided for a detention of 20 minutes. Settling tanks follow and provide a detention period of 90 minutes. These are cleaned by scraper mechanisms and the sludge, averaging 15.5 per cent solids, is pumped by centrifugal sludge pumps to sludge drying pond. Skimming devices should be installed on the settling tanks, the scum collected and pumped to the pond.

During the 1939 campaign the plant was operated for two weeks as a plain sedimentation plant, without the addition of Steffens house waste. The results were as follows:

	Raw Waste, P.P.M.	Grit Ch. Effl., P.P.M.	Removal by G. C., Per Cent	Final Effl., P.P.M.	Total Removal, Per Cent
Susp. Solids	1111	901	20.3	140	87.2
B.O.D.	289	256	10.8	201	30.3

On the basis of slicing 2,000 tons of beets daily, the solids in the waste per ton of beets was equivalent to 24 lb., of which 21 lb. was removed by plain sedimentation. The B.O.D. of the raw waste was equal to 6.2 lb., 1.8 being removed, leaving an effluent with a B.O.D. of 4.4 lb. per ton of beets.

For two months the units were operated as a chemical precipitation plant, using Steffens waste as the coagulant. The raw factory waste was first passed through the grit chamber as in the previous method of operation. Then it was mixed with Steffens waste averaging 951 p.p.m. suspended solids and 12,133 p.p.m. B.O.D. The results during this period were as follows:

	Raw Waste, P.P.M.	Grit Ch. Effl., P.P.M.	Mixture with Stef., P.P.M.	Equiv. Infl., P.P.M.	Final Effl., P.P.M.	Total Removal, Per Cent
Susp. Solids	1071	831	1371	1607	141	91.4
B.O.D.	321	273	907	919	358	61.2

The suspended solids in the combined factory and Steffens wastes was equal to 35 lb. per ton of beets sliced, 32 lb. being removed in the process. The total B.O.D. was 21.5 lb., 13.2 being removed by coagulation and precipitation.

The B.O.D. removals using Steffens waste were not in accord with previous results and are not indicative of average plant results. Difficulties were experienced with poor quality molasses in the Steffens house. During the last month of operation the B.O.D. of the effluent averaged 264 p.p.m., comparing favorably with previous experimental results. This should be accepted as a normal value, giving a removal of 71.3 per cent, and an effluent containing 6.2 lb. B.O.D. per ton of beets sliced. Foam resulted from too violent mixing of factory and Steffens wastes. The foam was controlled by eliminating the rapid mix and using only the gentle agitation of the coagulation mechanism. The resulting floc and removals obtained were not affected.

Wastes from a Sheep Skin Tannery

Studies were made on the liquid wastes from the sheep skin tannery of the Nelson Tanning Corp. at Muskegon, Mich. The tanning processes differ from those used for the hides of cattle in that no hair is removed from the sheep hides and no lime is used in the tannery. A complete description is given of the tanning process. The average flow of water was 155,000 g.p.d., containing 1,301 p.p.m. suspended solids, 1,062 p.p.m. B.O.D., and having a pH of 6.6.

An experimental plant was built to treat 450 gal. per hr. of this waste. Plain sedimentation and lime precipitation methods were used, operating the settling tank on continuous flow and on a fill-and-draw basis, with two hours detention for each condition. The average results were as follows:

Treatment	Suspended Solids			B.O.D.		
	Infl.	Effl.	Per Cent Rem.	Infl.	Effl.	Per Cent Rem.
Plain Sed. Cont. Flow	1184	680	43	1046	537	48
Plain Sed. Fill and Draw	1880	461	67	1285	873	30
1490 p.p.m. Lime Cont. Flow	918	469	46	1001	476	55
1700 p.p.m. Lime Fill and Draw	1980	497	73	1630	823	49

The author concludes that lime treatment using fill-and-draw sedimentation is to be recommended for this plant. The character of the waste changes so frequently that better control is possible by making tests prior to the addition of lime to each batch. About 14 lbs. of lime is required per 1,000 gal. of waste to bring about the small additional removal in solids and B.O.D. A sludge with a solids content of 3.9 per cent was produced, with a volume equal to 5.3 per cent of the original waste. This dries readily on sand beds.

By making some changes in tannery operations it may be possible to recover marketable fat by degreasing the breaks and fleshing machine wastes. In laboratory experiments these wastes were treated in a degreasing tank in which 1.25 gallons of technical acid were added per 1,000 gallons of waste to separate the fat. Aeration and skimming followed. The tests indicated that about 600 lbs. of fat could be recovered from the 16,000 gal. of these wastes flowing daily. Further studies are necessary to determine the commercial value of this process.

ROLF ELIASSEN

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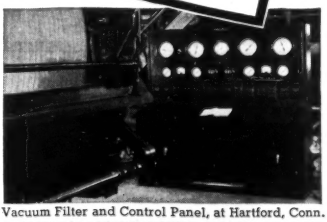
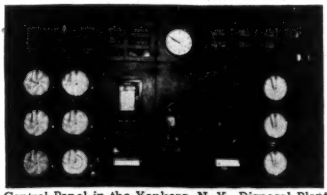


Vacuum Filter and Control Panel, at Hartford, Conn.



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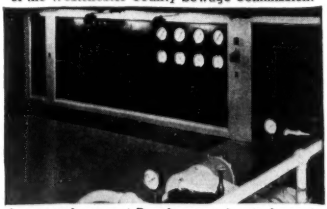

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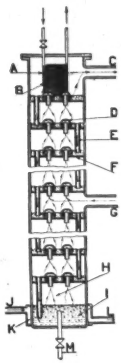

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B. Condensing purified chlorine
C. Purified chlorine outlet
D. Bubble cap
E. Downtake for reflux
F. Tray or plate
G. Raw chlorine inlet
H. Chloroform vapors
I. Chloroform and dissolved impurities
J. Steam inlet
K. Heating jacket
L. Condensed water
M. Drain for impurities

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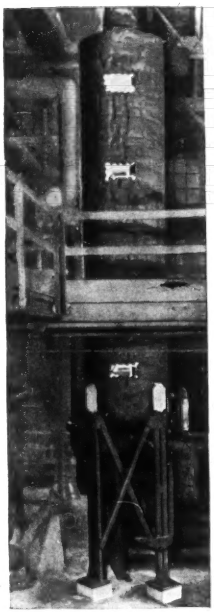

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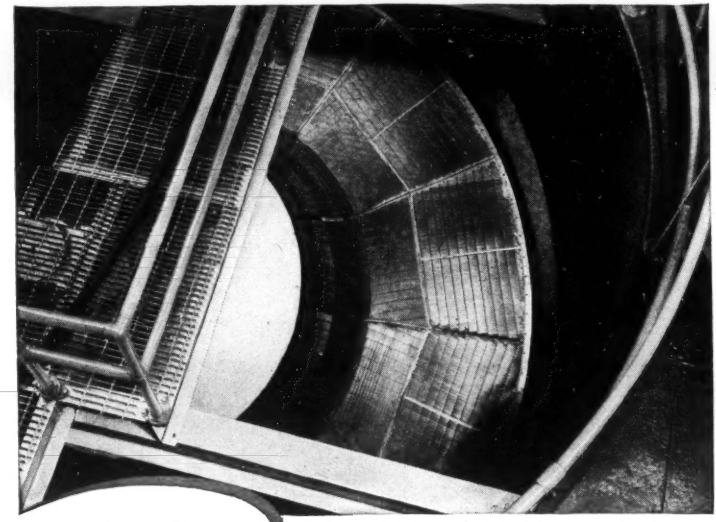

Everdur copper-silicon alloy screens in Congress Street plant of Bridgeport, Conn., Sewage Disposal System

Life of screen plates DOUBLED through use of EVERDUR!

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"NEITHER of our Bridgeport plants was built with grit chambers. As a result, wear on screen plates is greater than if so protected. The life of our screen plates was formerly about five years, but about 1931 we had a set made up of copper-silicon alloy (*Everdur*).

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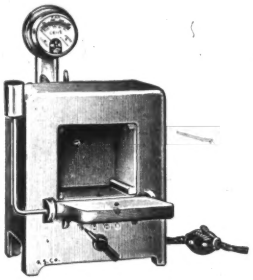

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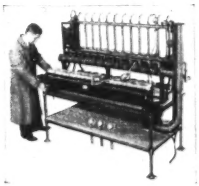

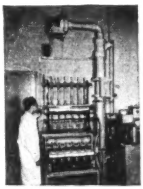

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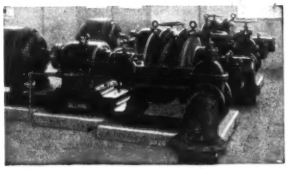

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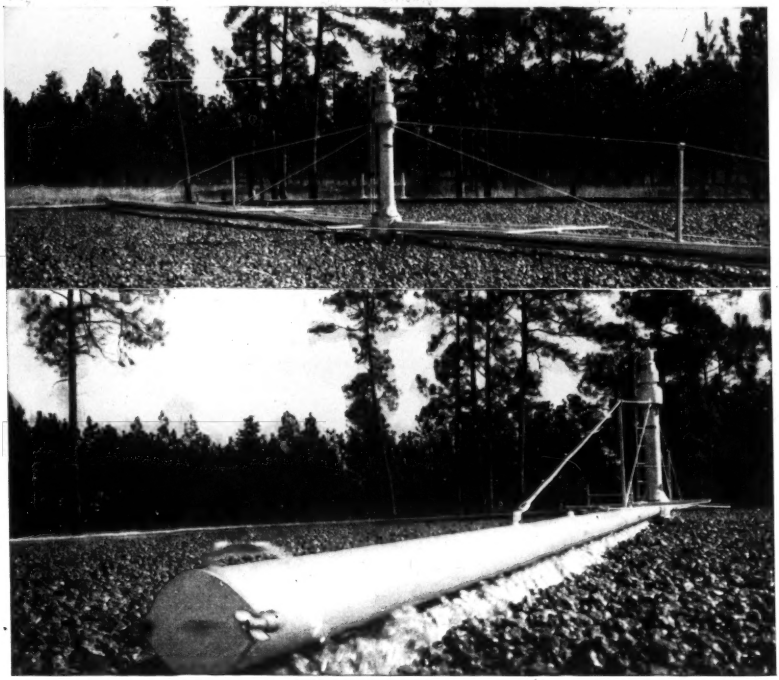

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More and More Modern Cities Authorize Disposal of Ground Food Wastes with Sanitary Sewage.

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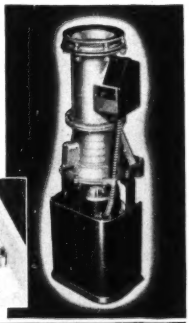
Complete information and authoritative reports on the Disposall's function in its relation to sewage treatment systems will be sent upon request. Write General Electric Appliance & Mdse. Dept. NR-0395, Bridgeport, Conn.



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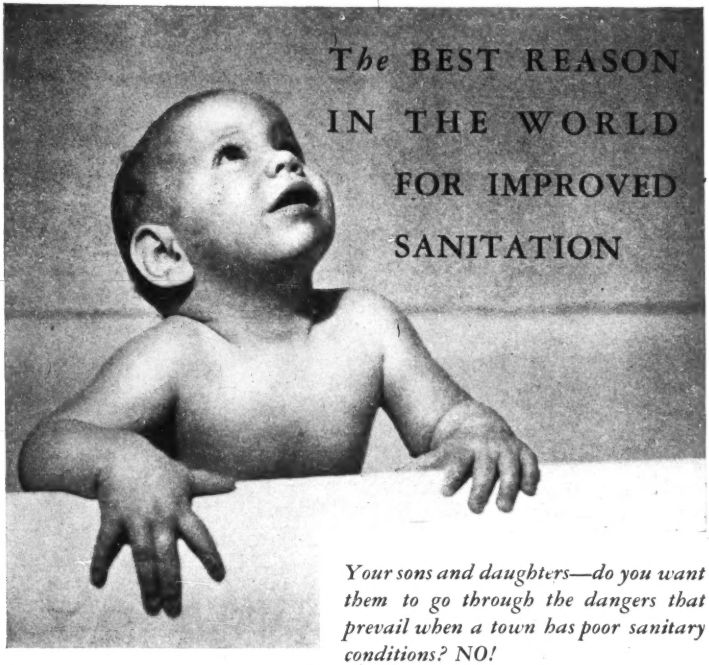

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That's the way the rest of the dads in your town feel, too, when you get right down to it. And that's the reason sanitary sewers are the civic improvement that pays the biggest dividends in health and wealth.

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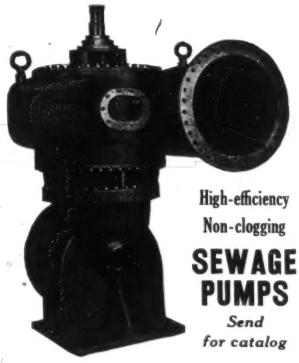

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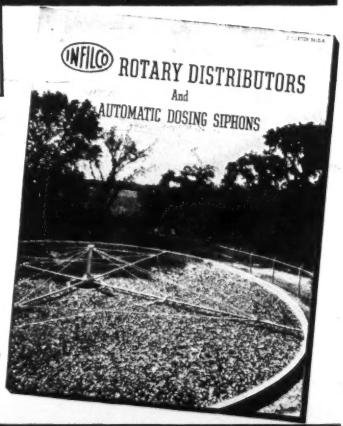

Only Infilco Rotary Distributors bring you so many important advantages such as these: full-opening end gates—mercury seal and protective bronze seal ring—corrosion-resistant nickel iron castings, etc.

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For a complete discussion of these and other features of Infilco Rotary Distributors write for a copy of Bulletin 2410-A.

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EQUIPMENT FOR CHEMICAL, BIOLOGICAL AND MECHANICAL TREATMENT OF SEWAGE

15 MONTHS LATER

INDEX TO VOLUME XI

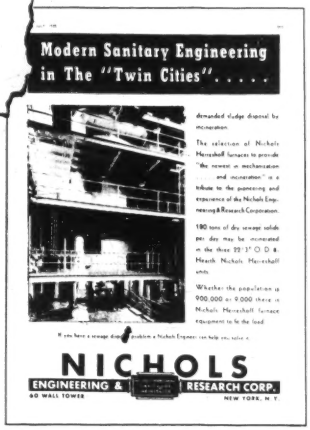
SEWAGE WORKS JOURNAL

VOL. XI NOVEMBER, 1939 No. 6

Special Articles

Incineration at Minneapolis—Schroepfer

THE ADVERTISEMENT BELOW WAS PRINTED IN JULY, 1938



Excerpts from conclusions of the final report prepared upon the completion of incinerator acceptance tests as printed in Sewage Works Journal, November 1939.

The incinerators are capable of incinerating the tonnage for which they were guaranteed, namely, 60 tons of dry solids per 24 hours for each incinerator. They have on occasion satisfactorily handled an overload of approximately 33 per cent.

The incinerators have complied with the provisions of the specifications relative to freedom from nuisances due to fly ash, odors and smoke. . . . The sludge was reduced to a clean ash, the combustible content averaging 1.6 per cent.

The requirements of the specifications relative to meeting certain guaranteed costs were fulfilled. The actual costs during the 90-day acceptance period were $4,559.68, or $0.455 per dry ton, as compared with the guaranteed costs as stated in the proposal of $7,084.04, or $0.707 per dry ton. Translating these costs to an annual basis the actual costs of incineration would be $18,492.03, as compared with the guaranteed costs of $28,729.71, or an annual saving of approximately $10,000 over the guaranteed costs.

Write "Incineration Headquarters" for data on how communities are disposing of solid wastes, including sewage sludge, screenings, grit, garbage or rubbish in a sanitary and economical manner.

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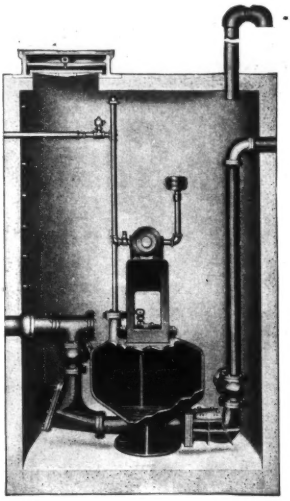

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SEWAGE WORKS JOURNAL

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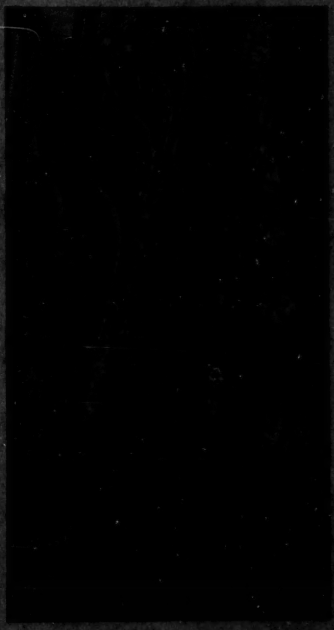

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